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CLIMATE CHANGE IMPACTS IN NEW ZEALAND: A CROSS-DISCIPLINARY ASSESSMENT OF THE NEED TO ADAPT BUILDINGS, WITH FOCUS ON HOUSING

**JONAS BENGTTSSON, JESSICA BENNETT, STEPHEN MCKERNON, BRETT
MULLAN, IAN PAGE**

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BENGTSSON JONAS, BENNETT JESSICA, MCKERNON STEPHEN, MULLAN BRETT, PAGE IAN

BRANZ Ltd, Moonshine Road, Judgeford, Porirua City, New Zealand

ABSTRACT

The scientific evidence is very strong: climate change presents very serious global risks and it demands an urgent global response. This paper is part of the dissemination phase of a research project assessing the need to adapt buildings in New Zealand to climate change based on medium-low and medium-high climate change scenarios from research by the National Institute of Water and Atmospheric Research (NIWA). The overall purpose is to determine the impact of climate change on the built environment and to generate a set of options for adaptation. The building sector's vulnerability to climate change is assessed through:

- Topology and condition review of the national building stock;
- House overheating conditions and energy consumption simulations; and
- A scenario-based social impacts study.

Adaptation options and recommendations are presented for a broad range of building-related climate change impacts. Economic modelling and cost-benefit analyses are used to investigate the economic viability of thermal adaptation.

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.

KEYWORDS

Climate change, adaptation, buildings, cross-disciplinary, New Zealand.

INTRODUCTION

Climate change will have broad and far-reaching effects on New Zealand society and its lifestyles, economy and governance. Climate change is expected to impact buildings and the urban environment in a number of ways. These include: an increase in heavy rainfall leading to more flash flooding events and subsidence; and drier conditions leading to clay soil shrinkage and raised fire risk. Other expected effects are: a change in demand for space heating and summer cooling; increased immigration; regional redistribution of land and property values; reduced access to insurance; and higher cost of carbon-intensive goods and services.

This paper is a selection and summary of the results from a cross-disciplinary assessment of the need to adapt buildings to climate change. The overall purpose of the report is to determine the impact of climate change on the built environment and to generate a set of options for adaptation. The focus is on houses, and although non-residential buildings are not examined in-depth, many of the impacts that apply to housing will also affect non-residential buildings. Due to size restrictions for this document we refer to the complete report (Bengtsson et al 2007) for a full presentation of results and methodologies.

METHODOLOGY

Climate change scenario projections methodology

The climate change projections by the NIWA form the foundation for assessing the impacts of climate change on the New Zealand built environment (see Mullan et al 2006).

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 two scalings – described as the 25th percentile (medium-low) and 75th percentile (medium-high) of the full IPCC temperature range – are simulated.¹ These

¹ The 25% and 75% limits were chosen to cover a reasonable range of possibilities while avoiding being alarmist by stressing extremes, in either direction, which some would view as unlikely.

scalings should not be considered extremes, but rather the lower and higher boundaries of probable developments. The climate scenarios in this report are based on two down-scaled global climate models: CSIRO and Hadley.

Social impacts scenario research methodology

This study used scenarios to construct strategically useful simulations of New Zealand's future housing system and its interactions with climate change. In common with other scenario methods, it seeks to initiate a *strategic conversation* (Van der Heijden 2005) about the future of housing by gaining input from experts in diverse sectors. Recent studies in New Zealand have explored the future of the housing sector with stakeholders (Saville-Smith 2000, Bates et al 2001, Bates and Kane 2006). This study employs a different approach to enrich the information available, but should be read in conjunction with these existing studies, especially the latter. The social part-study was carried out in four steps:

1. Key climate changes, potential social impacts and housing conditions were identified and projected for the years 2031 and 2081;
2. The projected changes were analysed and draft future scenarios were developed using qualitative/ soft systems analyses (Checkland 1981, Room and Britton 2006);
3. Draft future scenarios were explored with experts from diverse sectors to identify key impacts and adaptations, using one-hour phone or face-to-face interviews (sector experts) and a brainstorming group (householders). The experts explored the key influences that were identified in Steps 1 and 2. In total, 13 experts and eight householders provided strategic input into the development of this study. The total interview time was 17 hours.
4. Detail key social impacts and housing adaptations with respect to climate change.

The key changes in Step 1 above were the climate projections from NIWA, demographics, social variables, and wildcard variables. In summary, for the social scenarios we assumed an overall growth in the New Zealand population up to over five million people by the 2080s with larger Maori, Pacific Island and Asian ethnic proportions of the population and a decreased proportion of people with European ethnicity. The population was assumed to be ageing, with the median age rising from 35 years in 2001 to 55 years by 2081. An increase in single and couple households at the expense of two parent households was also expected.

Obesity and overweightness in the population were assumed to increase as a social problem, especially in the over 65 years age category. It was further assumed that there will be a rise in crime rate; immigration; percentage of the population working from home; development of telecommunication technologies; house mass production (with increasing imports lowering the price for householders and pressuring local manufacturers); the number and variety of sustainability initiatives (although they will be dependent for their success on the political, economical and social environment).

The wildcard variables used were: decline in global oil production (assuming virtually no production by the 2080s); percentage increase of the global population suffering from severe water stress (exceeding 75% by 2081); volcanic activity is assumed to remain significant enough to be included in civil defence and emergency management planning; and finally wars over access to natural resources and cultural/religious differences are assumed to continue to divert activity away from sustainability and quality of life which will engender economic hardship and shifts in migration patterns where New Zealand is typically viewed as an attractive alternative.

House thermal simulation and cost-benefit analysis methodology

A building stock analysis was used to identify two vulnerable and (for a large portion of existing buildings in New Zealand) representative building types.

For the identified house types the thermal performance and annual energy consumptions were simulated using the SunRel software modelling tool. These simulations were done for three locations (Auckland, Wellington, Christchurch) and five climate scenarios provided by NIWA (present day, and least change and most change for 2030s and 2080s respectively and abbreviated to PD06, C375, H325, H825 and C875 in the graphs). The simulations were performed for five insulation options per location. The base insulation assumed no wall, ceiling or floor insulation and single-glazed windows. The best insulation option assumed wall, ceiling or floor insulation (with R-values of at least 2.6 and up to 5.0 for the ceiling insulation in Christchurch) and with lowE argon-filled double-glazing. Exterior awning shades were placed just above all north-facing windows (and east and west-facing windows if they were in living areas or bedrooms) to reduce

solar gains. Ventilation in the form of opening windows was incorporated to assist the heat pumps in cooling the house.

Each model used heat pumps to heat/cool the house, with the heating set at 16°C from 11pm – 7am and 20°C from 7am – 11pm. Cooling was set at 25°C. The cost of a heat pump was \$3,000 each (on average replaced every 10 years) and there was a coefficient of performance of 3. Windows were assumed to be replaced every 30 years and awnings every 10 years. Window prices² were obtained from the industry and window awning prices were obtained from Rawlinson's.³

Economic 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 it is assumed that it would take 10 years to retrofit all the existing houses with no or poor insulation. Three timeframes were modelled: start now; start in 2015, or start in 2025.

Using QVNZ data it was calculated that the Auckland model represents 54% of the existing stock, Wellington 21% and Christchurch 25%. The demolition model used assumes a 110 years average life for the existing house stock built prior to 1978 with little or no insulation. About 1,700 of these houses are currently being demolished per year now. This number is assumed to increase up to 5,000 demolitions per year until about 2075, after which it will start decreasing over the following years.

Health costs were based on research by Chapman *et al.* (2005) that found that a household would spend approximately \$47 extra per year if they lived in an uninsulated house compared to 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% per year, with acknowledgement that the choice of discount rate for adaptations to climate change impacts is subject to debate and the development of energy prices is uncertain.

CLIMATE CHANGE SCENARIO PROJECTIONS FOR NEW ZEALAND

This section gives a summary of the climate change projections by NIWA (see *Table 1* below). The 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 inter-annual 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.

Table 1: Projected 50-year and 100-year climate change trends.

	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 0.16 m	0.23 to 0.52 m
Frequency of days >25°C	Increase	Doubling or more (except Christchurch)
Drought (1-in-20 yr events)	More frequent (exc. Hokitika)	As frequent as every 5–10 years (exc. Hokitika)
Wildfire risk	Increase, especially eastern parts	>+50% near Christchurch and other eastern parts
Days with frosts	Decrease	Half as often in 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	

² Double-glazing prices have been reduced by 10% from current prices to reflect the expected economics of scale 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. The use of double-glazing is widespread in the South Island, and the market size will more than double with the proposed changes.

³ *NZ Construction Handbook* (Rawlinson, Auckland, 2005).

	2030s	2080s
Hail	Increase in hail occurrences (still uncertain)	
UV radiation (comp. to 1980)	2% higher	0% (i.e. recovered)

PHYSICAL VULNERABILITY ASSESSMENT OF THE BUILT ENVIRONMENT

The main identified physical vulnerabilities to climate change in the built environment are: indoor overheating; inland flooding; coastal hazards; droughts and fire. Projections for changes in intensity of ex-tropical cyclones and extreme wind conditions are also discussed in this section as they could have potentially catastrophic impacts, yet the climate science remain uncertain. Impacts and adaptations are largely based on research by Camilleri (2000).

Increased overheating risk

For the 2030s, annual-average temperature increases by about 0.4 to 0.8°C, depending on the scenario. By the end of the century (the 2080s), the temperature is projected to rise by 1.0 to 2.4°C. Projected temperatures increase everywhere, with the exception of Hokitika in summer for the 2030s Hadley scenarios.

High temperature extremes will increase in frequency and low temperature extremes (e.g. frost) will become less common. Extreme temperatures affect living comfort, and consequently the need for either space heating in winter or air-conditioning in summer. Table 2 below provides quantitative estimates of changes in temperature extremes calculated using *weather generators* (Mullan et al 2001).

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

Max. temp >25°C	Present days	Additional days 2030s	Additional days 2080s
Auckland	21.3	6.9 to 14.6	25.9 to 52.6
Wellington	2.9	0.4 to 2.0	3.5 to 13.9
Christchurch	31.2	2.7 to 10.2	12.7 to 30.2

The future increases in Auckland and Christchurch would be enough to create a long summer *cooling season* lasting a month or more. Such prolonged discomfort is unlikely to be tolerated by many house-owners who would take adaptive measures, possibly by installing air-conditioning (and raising the greenhouse gas emissions from energy use). As will be discussed later in this paper, 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.

Increased rain and inland flooding

The amount of water held in the atmosphere increases with rises 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. Rises in extreme rainfall are considered likely, even where the annual average rainfall changes little or even decreases.

In general, 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. The relationship between flood events and extreme rainfall will vary with the characteristics of each catchment. For example, for small catchments or for the built environment with lots of paved surfaces run-off 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. Extra water can result in landslides which can directly undermine buildings or damage buildings.

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. With climate change the historical flooding Annual Exceedence Probabilities (AEPs) are projected to increase, meaning a rise in the frequency of flooding and 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 AEP e.g. a 4-fold

increase in the AEP could result in up to a 10-fold increase in the cost of building damage (Smith et al 1998). 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 this time it will be too late for changes in planning or Building Code requirements to reduce the impacts of climate change induced flooding on affected houses.⁴

Increased coastal flooding, erosion and rising water tables

Projected future global mean sea-level rises are consistent with the global mean temperature increases assumed in the scenarios of this report. Mean sea-level rises range 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. In addition to mean sea-level rise due to global warming, the sea-level is determined by a number of components such as tides, storm surge and long period oscillations e.g. annual seasonal heating and cooling by the sun (± 0.04 m to ± 0.08 m), El Niño-Southern Oscillation cycles (± 0.12 m), and Interdecadal Pacific Oscillation⁵ (± 0.05 m).

Coastal hazards 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. These interactions can operate over a range of different time and spatial scales, ranging from episodic storm events through to longer-term cyclic coastal change caused by seasonal, inter-annual and decadal variability (see MfE 2004a).

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 need to have a large *safety margin* for storm surges 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 effects caused by changes in sea-level.

The water table is expected to increase 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.

Wind and ex-tropical cyclones

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. Under climate change arising from rising 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 21st century progresses.

Changes in future storminess over New Zealand are still very difficult to quantify. The most robust feature is for poleward movement in storm tracks, which has its most marked effects in the winter season. On the other hand, in the current climate the westerly wind belt and embedded storms tend to move northwards to lie across New Zealand. There is currently low confidence in the projections for changes in strong winds (these vary between little change up to double the frequency of winds above 30 m/s by the 2080s – see MfE 2004b).

⁴ See Camilleri (2000) section 6, page for a discussion.

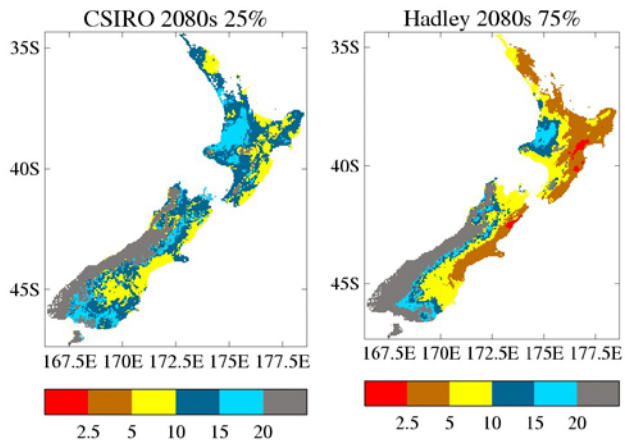
⁵ Longer “El-Niño-like” 20–30 year cycles of alternate positive and negative phases that effect the wider Pacific Ocean region, abbreviated as IPO. Since 1998 the IPO has been negative.

Drought and fire

Changes in drought risk are related to a combination of changes in evapo-transpiration 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). Droughts are expected to become more frequent in all regions considered⁶ 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 investigated in this study (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 rise by more than 50% by the end of the century around Christchurch and some other east coast locations.

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). 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.



Recommendations, costs and benefits for physical adaptation

Regions with high climate change exposure from increased risk of bushfire, flood and coastal hazards should be avoided or developed with due consideration of future climate change impacts. Properties vulnerable to coastal erosion may need to be protected using measures to reduce wave energy or possibly move or abandon houses which cannot be economically protected. 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. They should 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. Territorial Authorities should also allow for possible sea-level rise in new drainage systems, coastal infrastructure and buffer zones.

The total climate change adaptation cost calculated for the existing housing stock in Bengtsson *et al.* (2007) is approximately \$2.3 billion, which represents about 1.3% of the value of the housing stock. The expected benefit by the 2080s is estimated to at least \$4 billion in present value dollars.

SOCIAL EFFECTS OF THE IMPACTS OF CLIMATE CHANGE

Background

From the previous section's review of projected climate changes and assessment of building-related impacts it is clear that New Zealand will experience significant changes and impacts. A part-study by Supplejack Ltd (McKernon 2006) was used to identify the social impacts of climate change in relation to housing. This social study was based on a background of local and international research into social change in relation to sustainability, global warming, climate change and a number of related topics such as energy use and waste management.

The social meanings and impacts of climate change can be expected to vary considerably, by community and over time. Empirical studies since the 1960s have detailed the dynamics of change in relation to the social impacts of industrialisation, and consumption in particular. 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.

While adaptation to climate change and sustainable behaviour change are increasingly understood through the social sciences, they occur for the public as loosely-framed media and interpersonal communications about,

⁶ Auckland, Hamilton, Tauranga, Wellington, Nelson, Christchurch and Hokitika.

for example, bad weather and “being green”. Further, they arise conversationally – as topics of discussion – and are not framed as calls to action. 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 drunk driving) is alien to everyday ways of accounting for personal, day-to-day experiences and activities. In recent years a range of international and local studies have shown awareness of climate change has grown rapidly, and with this has come an increase in attitudes favouring action and a concern to find solutions for living. A smaller set of studies have explored the specific meanings given to climate change and the specific behaviours that result: these show the well-known gaps between awareness, useful attitudes, and productive action.⁷

Social impacts on housing

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 employed a scenario-building method to scope likely future societal and housing configurations in order to assess the range of likely social impacts of climate change. Some of the key impacts identified are:

- 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.
- 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 social tensions. Climate and social adaptations are expected to co-evolve.
- An ageing population highlights key social impacts: this population increasingly remaining in their own homes could result in a rise 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 results in higher vulnerabilities.
- Key forms of resilience are psychological toughness and community cohesion: evidence available 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.
- Social conflict is projected to be a major impact: climate change’s social impacts are 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.
- 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.

Recommendations for social adaptation

In order to ameliorate the impacts from climate change housing it is recommended that, as a broader strategic platform, adaptations are oriented to the more vulnerable and socially-excluded groups. As climate change adaptation will progress in combination and in parallel with other social changes and drivers, behaviour change programmes need to 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.

⁷ For example, research by EECA shows 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.

We recommend the development of a proactive approach that leverages research – such as this report – towards a coherent and effective sectoral response to climate change. Synergies may be achieved with initiatives that deal with health and other social issues. Housing adaptations can profitably be oriented to raise concern over storms/flooding/erosion/landslips as a threat to the New Zealand way of life, with particular impacts for coastal communities/houses. Loss of iconic housing locations, lifestyles and landscapes is a powerful motivator for public concern.

TOPOLOGY AND CONDITION REVIEW OF THE NATIONAL BUILDING STOCKS

This section summarises the building stock analysis which includes the typology describing the value of the segments, then details of the housing stock including numbers, location and other characteristics that are relevant to adaptation. The reviewed was in part done to identify building types in the building stock with specifically high vulnerability to climate change.

Capital value

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. This is followed by civil engineering structure (roads, bridges, other transport facilities, water/sewage/waste disposal, Telecom and energy infrastructure) at \$50 billion. The focus of this assessment is on houses, and although non-residential buildings are not examined in depth, many of the impacts that apply to housing will also affect non-residential buildings. 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. Industrial-type buildings (warehouse, factory and farm) can largely be ignored for climate change adaptation as they are usually fairly short-lived and simple buildings.

Housing overview

- 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 a 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 50 mm or less insulation.

A large number of houses constructed before the 1970s are in need of 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.

From the analysis of the existing building stock it was noted that approximately 390,000 or 51%⁸ of homes built prior to 1978 had not been fitted with any or sufficient insulation (this includes homes that have been retrofitted). Further, based on building stock analysis, we assumed that half of the existing pre-1980s stock can be represented by the small house and the other half by the medium house. The representative house types used are:

- small house – approximately 100 m², one-storey, timber weatherboard wall cladding, sheet metal roof cladding and timber floor

⁸ Using QVNZ and HCS (Clark et al 2005) data.

- medium house – approximately 150 m², one-storey, masonry veneer wall cladding, sheet metal roof cladding and concrete floor.

HOUSE OVERHEATING AND ENERGY CONSUMPTION SIMULATION RESULTS

This section presents the results from thermal building simulations, primarily for the two representative existing building types as identified in the previous section. All of the explored building techniques outlined in the methodology section can provide energy savings and energy efficiency to reduce the risk of overheating.

The multi-variable thermal simulations, based on *medium-low* and *medium-high* climate change scenarios, show that all simulated 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 during summer within their houses will be increasingly above the accepted comfort range (assumed 18–25°C). However, the simulations showed that comfort temperatures can be achieved with significant energy savings through each or combinations of: window shading (particularly on the northern sides); upgrading to double-glazing or better; upgrading to base insulation or better; and use of natural ventilation rather than use of mechanical cooling i.e. air-conditioning.

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 lowE and argon-filled double-glazed windows does give additional energy savings, but of lower magnitude and at a higher material cost.

Window shadings can also play an important part in 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.

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.



Figure 2: Sample of simulation output for cooling and heating energy consumption for five climate scenarios, three shading options and five insulation levels (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 filled, thermal break aluminium frame = 4).

Finally, homeowners benefit from maximising 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.

In the following section the economic costs and benefits are analysed in order to explore economically optimal solutions for the two representative existing building types as identified in the previous section.

COSTS AND BENEFITS FROM ADAPTING TO TEMPERATURE INCREASE

The simulation results from the previous section were used to compare net benefits of selected adaptation option. The economic modelling suggests that insulation retrofitting of the existing housing stock should be done as soon as possible since the Net Present Values (NPVs) 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, if feasible, it is recommended that all homes have ceiling, wall and floor insulation with no awnings installed. None of the models indicate that it is best to install awnings. This is not because they do not provide significant energy savings, but because of the cost of installing them. While awnings provide good sun protection and energy savings they are quite expensive (\$4,000 to \$10,000 per house depending on size).

Double-glazing significantly reduces energy consumption, but in no situation modelled does it provide a greater NPV than single-glazing. Still, it is recommended that a double-glazing retrofit be considered in all regions due to superior energy performance and demonstrated strong positive NPVs. Overall it was shown 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. Due to cost, 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.

Due to resource constraints a wide range of situations or house types were not modelled, but rather typical house sizes by three locations to represent a sizable proportion of the stock. Ideally thousands of different homes should have been modelled and the results then averaged. Our analysis does not attempt to fine tune optimal levels of insulation; the goal is to indicate broad trends over time.

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

CONCLUSION

Robust scientific projections show that climate change will significantly affect the New Zealand built environment. Major impacts are expected from inland and coastal flooding, building overheating, and increased occurrence of droughts and fire risk in the eastern parts of the country. It is essential that the climate-change planning process starts now, given the longevity of housing developments and infrastructure in increasingly at-risk communities. Costs to homeowners and the national economy, and social disruption and tension, can all be avoided by developing and retrofitting with consideration of increasing climate exposure and vulnerability.

The inventory of the building stock suggests that climate change adaptation should focus on residential, institutional and commercial buildings. Industrial-type buildings can largely be ignored for climate change adaptation as they are usually fairly short-lived and simple buildings.

Social impacts from climate change will be intertwined with other major social changes. A more detailed analysis of social impacts suggests these will be powerfully shaped by dynamics of social inclusion and exclusion. The prospect of increased damage means many communities may need to re-assess their futures. The social research, involving a broad range of experts from outside the building sector, warns that

significant social disruption and conflict over changes in the value of land in coastal areas will occur, especially where wealthy enclaves suffer significant loss in value. The relatively mild 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 growth in the housing sector.

Building overheating from increase in frequency and severity of summer temperature extremes can be avoided by passive design and retrofit. Thermal simulations show that comfortable indoor summer temperatures can be maintained in all climate change scenarios explored by adapting to overheating with window shading and natural ventilation. The simulations also show significant year-round energy savings in all buildings using double-glazing or high-performance glazing, and improved ceiling and wall insulation.

To maximise economic benefits insulation retrofitting of the existing housing stock should be done as soon as possible. Thermal insulation comes out the most favourable as currently we under-insulate our homes by a huge amount. The second most favourable retrofit is upgrade from single-glazing to double-glazing. While awnings provide good sun protection, in no situation do they provide a greater NPV than having no awnings. It is therefore not recommended that awnings be installed if the primary objective is lower NPV.

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