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Implications of Climate Change for the Construction Sector: Adaptation and Mitigation Strategies and Revised CCSI

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Preface

This is the fourth and final report in a series prepared during a 3 year research project examining the implications of climate change for the construction sector. This report presents adaptation and mitigation strategies for houses and offices buildings to minimise the adverse impacts of climate change. It includes methods for assessing whether adaptation for climate change is necessary, and some suggestions for possible adaptation strategies. Many aspects of climate change have been discussed in detail in the earlier reports in this series, so the reader is referred to these for further information.

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IMPLICATIONS OF CLIMATE CHANGE FOR THE CONSTRUCTION SECTOR: ADAPTATION AND MITIGATION STRATEGIES

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M. J. Camilleri

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ABSTRACT

Two reports in this series (BRANZ SR 94 and SR 96) identified the many ways that the built environment may be affected by climate change, and the most important of these impacts were found to be increased inland and coastal flooding, overheating, and tropical cyclones. The Climate Change Sustainability Index (CCSI) (BRANZ SR 95 and SR 96) was developed to assess the vulnerability of houses or office buildings to these impacts.

In this report the CCSI is extended to include adaptation and mitigation strategies which if adopted would reduce the vulnerability of a house or office building to these adverse impacts of climate change.

Adaptation strategies are provided for overheating, flooding, and tropical cyclones, and mitigation strategies for greenhouse gas (GHG) emissions for houses and office buildings. These strategies have been published in summary form in BRANZ Bulletin 144: Coping with climate change.

Buildings that utilise passive solar design principles are less vulnerable to the impacts of climate change. The benefits include reduced overheating, reduced energy use and costs, reduced greenhouse gas emissions, improved comfort, and less reliance on energy systems that may be adversely affected by climate change.

Reducing lighting and equipment loads in office buildings can reduce overheating, and reduce GHG emissions, and is readily achievable with existing technology.

A precautionary approach to flooding and storm damage by local authorities is needed to avoid creating new and expensive problems for the future, particularly in the continuing development of floodplains and vulnerable coastal strips. Following the processes and patterns of the past is insufficient to protect against the increasing risks of climate change.

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1. INTRODUCTION

Based on current climate change projections, New Zealand buildings will suffer significant impacts sometime 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 this climate change threat may be brought about to ensure that buildings in the future are more resilient to changes in climate.

This report is intended as a source guide for people who want to assess how climate change may affect a particular type of building, and explore what prudent, effective and economical steps could be taken to adapt and mitigate the impacts. The main stakeholder audience includes researchers, policy makers and planners from central and regional government. It is not intended as a DIY manual for construction professionals, or home owners, though information relevant to this audience is included. Future work will take the information and adapt it to a variety of audiences, which could include territorial authorities, builders, designers, and building owners.

1.1 Objective statement and preliminaries

This report forms part of Objective One in the FRST programme BRA605. The objective statement is as follows:

Develop adaptation and mitigation strategies that could be used by stakeholders to reduce long-term disruptions due to major environmental variation, including Climate Change, by:

- *developing a set of criteria that advises stakeholders if their building requires adaptation to selected Climate Change impacts, based on the building form and other factors;*
- *developing a set of practical recommendations for stakeholders for modifying the building physical envelope or immediate environment that would improve the Climate Change Sustainability Index rating;*
- *extending the Climate Change Sustainability Index to include these adaptation and mitigation strategies.*

1.2 Overview of structure

The CCSI provides the basis for assessing the vulnerability of buildings to the impacts of climate change [Camilleri and Jaques (2001), Camilleri (2000b)]. This previous research indicated that the following three climate change issues were likely to be potentially serious and have widespread impact on houses and office buildings: flooding (coastal and inland); overheating; and tropical cyclones and storms. In addition, responses to the Kyoto Protocol to reduce GHG emissions are likely to require adaptation of buildings, and changes in costs, and hence are an indirect impact of climate change.

Adaptation strategies are developed in this report for the three direct impacts, and mitigation strategies for the indirect impact of GHG emissions reductions. Only an outline of the information needed to assess the need for adaptation, and how to carry out that adaptation is given. More information, for example construction details, or precise sun-angle calculations etc, may be found from other sources.

The general format for each climate impact analysis is as follows:

- a method for assessing the severity of the impact (based on the CCSI)
- decision criteria for determining if adaptation is necessary
- adaptation or mitigation options for new and existing buildings, and discussion of their effectiveness and feasibility.

In addition, for the overheating and GHG emissions only, generic house types are given that allow for very quick assessment and decision. The coverage of the adaptation and mitigation strategies for houses and office buildings is as follows:

	Houses				**Office Buildings**	
	Overheating	**Flooding**	**Cyclone**	**Reduce GHGs**	**Overheating**	**Reduce GHGs**
Assessment	✓	✓	✓	✓	✓	✓
Adapt Existing	✓	✓	✓	✓	✓	✓
Adapt New	✓	✓	✓	✓	✓	✓
Generic	✓			✓		

Table 1. Coverage of adaptation and mitigation strategies

1.3 Stakeholders

The following stakeholders are identified as key audiences for climate change adaptation and mitigation strategies.

For houses:

1. House-owners
2. House-occupiers
3. Regulators (Building Act and Building Code)
4. New house purchasers
5. House builders
6. Local authorities
7. Financial interests (banks, investors, insurance companies).

For office buildings:

1. Office building owners
2. Office building occupiers
3. Regulators (Building Act and Building Code)
4. New office purchasers
5. Construction companies

6. Local authorities

7. Office building investors.

This report contains information that could be used by each of these stakeholder groups to adapt for climate change. However, recommendations are not customised for each particular stakeholder group. This process will be started in a subsequent programme, which aims to disseminate the information to many of these stakeholder groups in an effective and useful way.

1.4 Adaptation needs by age of building

Adaptation to the direct impacts of climate change is only needed for buildings that will still be standing and have a useful economic life concurrent with climate change impacts. An analysis of housing mortality is given in Appendix A, page 22, using a simplification of the model of Johnstone (1995), to derive estimates of the likelihood of houses surviving until 2030 and 2070, at which time the climate is likely to be significantly different from current norms. The decision criteria derived from this analysis are that on a nationwide basis:

1. Houses built before the 1920s do not need to be adapted,

2. Houses built in the 1920s to 1940s should be adapted for the moderate levels of climate change for 2030,

3. Houses built in the 1950s and later should be adapted for the more extreme climate change of 2070.

Note that this applies to populations of houses, so it is not recommended that pre-1920s houses as a population be adapted for climate change, as only a small fraction of these houses are likely to survive long enough to actually be affected by climate change. Therefore, any large-scale adaptation programme for 1920s houses would likely be wasteful. Adaptation of the small fraction that does survive might be worthwhile, but these houses cannot be identified readily now. Buildings that have a high intrinsic value (e.g. historic buildings) are not covered by these criteria.

No predictive or forecasting model of office building mortality in New Zealand could be found, and as it seems that such mortality data or models is not available, no age-based decision criteria were developed for office buildings.

Note that this does not apply to GHG emissions reductions. Measures to reduce emissions, which may be cost effective in the short to medium term, are likely to be implemented in only a few years as part of the National Energy Efficiency and Conservation Strategy.

2. OVERHEATING: HOUSES

Increased outside air temperatures will increase the extent and duration of overheating in houses, unless adaptation takes place. This may cause nuisance to house occupants, and a possible health hazard for susceptible people (e.g. the young and elderly).

2.1 Assessment and decision

The assessment is made using the overheating component of the CCSI for houses as described in Section B.1, page 25.

Overheating mitigation 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 from severe overheating already.

The assessment and decision for generic house types is discussed in the next section.

2.2 Overheating for generic house types

A number of generic house types are identified here that have broadly similar solar window to floor area ratios (SWR), as an easy means of approximating their overheating risk. In New Zealand, there is a large variation in the area, number, shading, and orientation of windows in houses. In creating a number of generic house types, a limited survey of books and house plans relating to New Zealand houses was carried out. Where possible, floor and window areas, and shading were measured from house plans, to estimate their SWR. Sources of measurements were Carrad; Watkins (1995-96); Bonny, Reynolds, and Sims (1988); and Salmond (1986).

In general, a trend to larger glazing areas was apparent with the more modern houses. Houses such as villas, cottages, and bungalows built in the early part of the 20th century generally had a modest area of glazing, often well shaded by eaves and verandahs. Glazing areas seem to increase markedly after the 1960s, especially with the introduction of ranch sliders and aluminium joinery, and the trend continued into the 1990s. The size of eaves also appeared to decrease for houses after about 1980. Many 1960s and 1970s houses have well proportioned eaves that provide effective shading for windows (though not ranch sliders) from summer sun, however these eaves were often smaller in size or eliminated in houses of the 1980s and 1990s. Architectural feature houses often had a combination of large glazing areas with neither eaves nor effective.

The categories for generic buildings for overheating are as follows:

1. Early 20th century villas, cottages, bungalows, with/without verandah
2. 1940s or 50s state houses – timber frame, modest window areas
3. 1960s or 70s ranch style houses
4. 1980s ranch style houses
5. 1970s or 80s low-cost houses
6. 1980s or 1990s premium houses with small or no eaves and large window areas.

House Type	Solar Window/Floor area ratio range (%)	Overheating Risk (Wellington)	Recommended Adaptation (Wellington)
1	0-10	Low-Medium	None
2	5-15	Medium-High	None, or increase shading
3	10-30	High	Shade north through west facing ranch sliders and large windows
4	10-45	High -Very High	As above
5	10-20	High	As above
6	20-50	Very High	Shade if possible, otherwise reflective glass and/or ventilation

Table 2. Typical window/floor area percentages and overheating risks for New Zealand house categories in Wellington.

2.3 Strategies to reduce overheating

Jaques (2000) examined a variety of mitigation strategies to determine how effective they were in reducing overheating. In order of most to least effective they were:

1. Reduce solar gain
2. Increase ventilation
3. Increase insulation
4. Use thermal mass, if available
5. Use air-conditioning.

Strategies for reducing overheating should be taken in this order, depending on feasibility. For new houses improving most of these aspects is both easy and inexpensive. For existing houses it is generally more difficult and expensive to adapt, though opportunities arise during substantial renovations. During renovations, all but thermal mass can be done readily, though probably less effectively and at greater cost than for a new house.

Note that reducing overheating by reducing solar gain can result in an increase in space heating needs, if winter solar gain is decreased. Passive solar design can be used to exclude summer sun, whilst admitting winter sun, to optimise both comfort and energy use.

Some more detail is given in the following sections on how some of the strategies may be implemented.

2.3.1 Reducing solar gain

If overheating is a problem, then reducing solar gain can be brought about by the following measures, in order of most to least effective:

1. Reduce window sizes
2. Shading by eaves or overhangs
3. Shading by trees, shrubs or screens
4. Reflective glazing

5. Internal reflective blinds
6. Double glazing.

Note that tinted glazing creates a hot glass surface which may cause discomfort.

North facing windows: External shading is very effective if properly designed to cut out the summer sun, but allow in the winter sun. For recommended awning to window sizes see Donn and Van Der Werff (1990). Windows that go to floor level, such as ranch sliders or French doors, can be problematic.

West and east facing windows: Both west and east facing windows are difficult to shade properly, as awnings or eaves are not very effective for low summer sun. Side screens are effective, as are deciduous trees and shrubs. It is much more important to shade west windows against afternoon sun, than east windows for morning sun.

For new houses, design window sizes, orientation, and shading so that the CCSI overheating rating is in the low risk range.

For existing houses, increase shading by using eaves, awnings, pergolas, or shade plants as appropriate.

If improving the shade is not feasible for new or existing houses, consider changing or treating the window glass, or internal reflective blinds.

2.3.2 Ventilation

Overheating can be reduced by increasing the amount of ventilation. This does not cure the problem of excess solar gain, but does improve comfort. The higher the ventilation rate, the greater the cooling, with the upper limit reached when the air-movement is disturbing to occupants, or the internal air temperature equals the external air temperature.

Extractor fans can provide a range of ventilation rates, with good control that does not depend on the outside wind and weather conditions as passive ventilation does. Jaques (2000) used an absolute maximum passive ventilation rate of 10 air changes per hour (ACH) with all windows open, and the simulation results from the report indicated that the sensitivity of temperature to ventilation rate at 10 ACH was about 0.5°C per ACH. This cooling of ~5°C at 10 ACH would alleviate the modest levels of overheating modelled by Jaques (2000), and lower ventilation rates would be less effective.

Extractor fans need to have sufficient capacity to be useful, with a ventilation rate of 10 ACH requiring 800 l/min for a 4m x 5m x 2.4 m room. Most modest sized fans (e.g. a small sized bathroom extractor) have sufficient capacity for this application. Care must be taken to ensure that the fan will not de-pressurise the house, causing chimneys and flues from gas appliances to flow in reverse, trapping poisonous fumes in some other part of the house. The advantages of fan forced ventilation are that it is fairly cheap to install, requires little, if any, modification of the house, is secure, operates on demand, and can be controlled by a thermostat or timer. Disadvantages are the installation and operating costs, potential noise, and need for user control.

Ceiling fans recirculate air in the room, and can promote ventilation if windows are open. Comfort is also improved by increased air movement, which increases perspiration loss from the skin to assist cooling.

Some passive options for increasing ventilation are listed below, though it may be difficult to achieve a high enough ventilation rate to significantly improve comfort under some conditions, such as days with low wind or external air temperatures that are already at uncomfortable levels.

1. Passive stack ventilation (e.g. through roof-lights or clestory windows)

2. Passive vents in windows or walls

3. Windows open on security latch.

Passive stack ventilation requires the vertical movement of air. In its most basic form the combination of open low windows or vents on one side of a house, with high vents or windows on the opposite side, may be enough to achieve effective passive ventilation. The extra height in two-storey houses may make for more effective passive ventilation, especially important as the upper storey could otherwise trap rising hot air, and be much warmer than the lower storey.

Passive vents and secure open windows are a less controllable method of ventilation. Unless the flow-path of the air creates a passive stack, the ventilation rate depends on the wind speed. This means that on hot days with light winds, the amount of ventilation may be insufficient. To work best, the vents should allow for the cross-flow of air through a room, or through the house.

2.3.3 Insulation

Houses insulated to the requirements of the current NZBC Clause H1 are likely to be approximately 1°C cooler than an uninsulated house of the same design. A superinsulated house (approximately double the insulation of H1) could be another 1-2°C cooler. Additional insulation, particularly in the roof space, can reduce overheating, with significant reductions in winter heating requirements and improved year-round comfort.

For new houses fully insulate the roof, walls, and floor, and use as much roof insulation as practicable. For existing houses, increase insulation in all areas, especially the roof.

2.3.4 Thermal mass

Adding thermal mass is generally impractical in an existing house, unless an addition is made. An exposed concrete floor (or covered by dark coloured tiles or vinyl) acts as effective thermal mass, and can reduce overheating. Thermal mass works best when integrated into a passive solar design strategy for the house. See Donn and Van Der Werff (1990) for detailed information, or EECA (2000).

2.3.5 Air-conditioning

Air-conditioning is currently uncommon in New Zealand houses, perhaps because in contrast to other countries, long periods (weeks to months) of continuously uncomfortable day and night outside air temperatures are (as yet) unheard of. Air-conditioning can be used as a quick-fix solution to some overheating problems, though in many cases taking some of the other steps to control overheating documented here could make air-conditioning unnecessary. Properly designed and installed air-conditioning can eliminate some types of overheating, though with high initial ($2-3000 for a single unit system) and running costs. If overheating is caused by excessive amounts of east or west glazing, the solar gains may be higher than an air-conditioner can handle. Air-conditioning does not deal with direct solar radiation, which can cause discomfort and glare. External shading is required in this situation. If air-conditioning is chosen, a reverse-cycle air-conditioning system can also provide heat for space heating, at about a third the running cost of electric heating.

For new and existing houses, explore other mitigation options before installing air-conditioning, as they may partly or wholly eliminate the overheating problem.

3. OVERHEATING: OFFICE BUILDINGS

3.1 Assessment and decision

The assessment is performed using the overheating CCSI for office buildings as described in section B.2, page 27. If the building has a CCSI score of 1 or less, then the building is likely to suffer from significant overheating at times during summer, and some modification is recommended to improve the current overheating performance. Lower ratings indicate worse overheating, and independent assessment for the particular building is advised.

3.2 Adaptation strategies

The causes and solutions for overheating in office buildings can be complex, and specialist advice is recommended to develop optimal solutions.

Reducing lighting and equipment loads is often the easiest and most cost-effective measure, especially for existing buildings, as a reduction of only 10 W/m^2 will reduce internal temperatures by about 1°C (Energy Group, 2000). It is feasible for nearly all office buildings to reduce lighting intensity levels to at most the current NZBC standard of 18 W/m^2, and down to 9 W/m^2 or less. This may require:

1. Changing light bulbs or tubes to more efficient types, or reducing the number
2. Changing fluorescent light ballasts to high-frequency, high efficiency types
3. Changing light fixtures and reflectors
4. Changing lighting controls
5. Installing daylight dimmers.

Note that reducing lighting loads does not mean reducing lighting levels, which could have a negative effect on the performance of the occupants.

If additional protection from overheating is desired, then increased ventilation and air circulation rates, or reduction of solar window gain are required. Reduction of solar window gain can be achieved most easily by either shading the windows with awnings or overhangs, or installing reflective glazing, or by installing heat reflective internal blinds. Cost, ease of installation, and maintenance will be an important part of the decision.

For new office buildings, a thermal design strategy should be developed early on in the design process to minimise the need and demand for air-conditioning.

Saville-Smith (1999) found that the current perception in the office building market was that air-conditioned buildings attracted a price premium, and are considered high quality office space. Fitting un-conditioned buildings with air-conditioning appears to happen frequently as part of office building refurbishment, though with good design options, this option could be rendered unnecessary, or be implemented at a reduced initial operating cost.

4. FLOODING: HOUSES

The incidence, and severity of flooding may increase as a result of climate change. This may expose buildings to increased flooding and increased damage, and damage by erosion and landslip. The real cost of flooding to people is far more than the financial cost of physical damage and repair – it may take weeks or months before the house is habitable after flooding, with the loss of many personal items, and it can be a very stressful experience.

4.1 Assessment and decision

Assessment is carried out according to the CCSI in Section B.3, page 29. If the house scores a -2 or -1 then some adaptation is strongly recommended. If the houses scores 0 then some adaptation is recommended. If the house scores 1 to 5 then adaptation is not necessary to maintain flooding risks below the currently acceptable level, though adaptation could provide greater protection.

No factors or groups of houses were identified that could be described as "generic" in terms of vulnerability or adaptation to flooding risk.

4.2 Urban flooding

The risks of urban flooding may fall outside the scope of the CCSI. As urban drainage networks are complex systems, unexpected flooding may occur in high rainfall events, or if drains and outlets become blocked. An increase in the capacity of urban drainage networks is needed to allow for the increased incidence of extreme rainfall with climate change.

4.3 Adaptation strategies

There are a number of options for reducing the risk and impact of flooding:

1. Reduce risk of flooding

2. Reduce damage potential of flooding to building and contents

3. Improve ability to recover from flooding

4. Flood preparedness.

4.3.1 Reduce risk of flooding

The risk of flooding may be determined by factors outside of the property boundary, for example flood protection schemes, which cannot be modified by a single house owner. Within the property boundary there are a variety of steps that can be taken to reduce the risk and severity of damage should flooding occur. These include raising or moving the house, flood-proofing (see next section) or building a small levee or flood-wall immediately around the house.

Note that the risks of flooding may not be known in areas of new development, and may not be limited to low lying areas.

Exceeding the minimum floor level clearance requirements for the area can substantially reduce the risk of flooding damage. This is probably more easily achieved with a suspended floor (concrete or timber), than a concrete slab-on-ground floor, though some polystyrene raft slab systems can give large ground clearances. A pole house can give a very high floor level for little or no extra cost. Consider building a multi-storey house, as it is only likely to be flooded on the ground floor, which could reduce the cost of flood damage by 50% or more, and allow faster reoccupation, especially if services and high-cost rooms such as bathrooms and kitchens are not on the ground floor.

Ensure foundations are strong, and can resist being undermined by erosion or scouring by flood waters.

4.3.2 Improve ability to recover from flooding

Once flooding has occurred, a building needs cleaning, drying, and repair before it can be re-occupied. By choosing water-resistant materials, and flood-proofing key building services, the cleanup can be made faster and less expensive. Access to internal walls is needed for cleaning, and repair of services, which may involve ripping out and replacing part of the wall linings. By using water resistant materials, replacement may not be necessary. Table 3 details the flood-resistance of some common building materials. Materials listed here as water resistant should withstand direct contact with flood waters for more than 72 hours, and require at most low cost cosmetic repair (such as painting).

	Water resistant	**Not water resistant**
Insulation	Closed cell foam (polystyrene or polyurethane)	Fibreglass, mineral wool, wool, cellulose, foil
Floors	Concrete, bare or coated Floorboards, durable or treated timber Concrete or clay tile	Particleboard, MDF, plywood[1] Ceramic tile[2]
Walls	Fibre-cement Concrete block Durable or treated timber PVC Brick (glazed or faced)	Particleboard, plywood[1]
Interior	Concrete block Fibre-cement Durable or treated timber	Plasterboard Plywood[1] Hardboard Softwood Carpet or vinyl Particleboard

Table 3. Water-resistance of some common building materials (adapted from FEMA (1993)

To make building services water resistant, install vulnerable equipment, such as wiring, hot water cylinders, meter boards etc, above possible flood levels or as high as practical. Plastic coated electrical wires should be adequately waterproof provided that the ends are not immersed, but junctions, joints, outlets, and switches are not, and will need cleaning and/or replacement. For example floor level outlets might need replacing after flooding, and perhaps their wiring also. If the outlets were above floor level, it its less likely that the outlet or wiring will need to be replaced after flooding. Other fixed appliances such as stoves, hot water cylinders etc also need cleaning or replacement. By mounting these appliances as high as possible, damage and disruption can be minimised.

[1] Marine grade or CCA treated plywood is water resistant.
[2] Resistant to clean water flooding only if has acid and alkali resistant grout. Otherwise not flood resistant.

4.3.3 Flood preparedness

Being prepared for a flood, and knowing what action to take can dramatically reduce the damage and disruption caused by flooding. There are many steps that can be taken to reduce the damage and disruption caused by flooding.

Flooding awareness:

- recognise that a flood could occur at any time
- consider leaving a key with neighbours, friends, or relatives if you are away, with instructions on what to do
- be prepared for forced evacuation with a survival kit of food, clothing, and essentials, and a getaway kit of essential medications and personal items.

Before flooding occurs:

- raise valuables above likely flood waters
- turn off electricity, gas, and water supplies[3]
- close all internal and external doors and windows to minimise the amount of debris entering rooms.

Contact the local council, Civil Defence or Emergency Management Office for more information on flood preparedness.

4.4 New house recommendations

Many options are available to reduce the flooding risk and damage potential when building a new house. The best option may be to not build on a vulnerable site. In order of priority:

- don't build on a flood-prone site[4]
- Be prepared for flooding
- exceed minimum floor levels
- consider multi-storey construction
- use water-resistant materials
- install essential, vulnerable equipment as high as possible.

BRANZ Bulletin 308: *Restoring a house after flood damage* is a useful guide, not only in dealing with the aftermath of flooding, but also in minimising the damage when flooding occurs.

[3] To prevent, respectively: the risk of electrical shorting or electrocution; uncontrolled venting of gas from appliances if safety shutoffs fail after inundation; and the contamination of the household water supply, or backflow of floodwater into the mains supply.

[4] Gaining a building consent, or having a clear land title does not guarantee a site is not flood-prone.

4.4.1 Existing house recommendations

Retrofitting for flooding is more difficult than building a house to be water-resistant in the first place. However it is often done after a house has been flooded, which is a waste of resources that could be spent more productively.

Costs are likely to be considerably more at the retrofit stage than at construction, which may preclude some measures. Some measures in particular include

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

Currently, there is no general relocation, assistance, or compensation scheme available in New Zealand for people whose houses have been condemned because of flooding. In some cases, limited assistance (usually financial) is given by local authorities, and for a major flooding disaster, national government assistance might be provided. This places a major (often insurmountable) burden on the house owners, and begs the question of how well the current systems will deal with a gradually increasing risk of flooding. Unless changes are made, the burden is likely to fall on individual house-owners, or perhaps local authorities if legal remedies are effective.

5. TROPICAL CYCLONES: HOUSES

With climate change there is the possibility that tropical cyclone activity could increase, increasing the likelihood and intensity of severe weather, primarily in the North Island. If it does increase, then storm, wind, flood, and erosion damage would become more frequent and costly. Current climate change research does not provide consistent scenarios of changes in tropical cyclones in extra-tropical areas such as New Zealand, but it is hoped that in the near future such projections become more reliable.

5.1 Assessment and decision

Assessment is done using the CCSI in Section B.4, page 32. As there is little certainty about the likelihood of increased extra-tropical cyclones, it is not recommended that houses in general be adapted for the possible increased risk at this stage. The following decision criteria may by used as a interim precautionary measure.

If the CCSI assessment for tropical cyclones is 0 or less, then it would be prudent to ensure that the structural strength of the house is comparable to modern standards. If the CCSI assessment for inland or coastal flooding is less than or equal to 0, then it is recommended that measures are taken to reduce the risk or damage potential.

5.2 Adaptation strategies

For adaptation strategies for flooding, see Section 4 above.

Houses built to earlier building practices or standards may have bracing and structural strength that is inadequate by modern standards. In addition, a loss of structural strength occurs with age due to such factors such as deterioration of connectors and materials by corrosion, fatigue, rot, and chemical change. Some houses built to earlier standards (pre-1992) may need to be upgraded to give structural strength comparable to the current standards (NZS 3604:1999, and NZS 4203:1992). The most important and feasible areas for upgrading are in the roof structure (including roofing fasteners, batten to rafter connection, and rafter to wall connection), and in sub-floor fasteners. Upgrading can be done as a part of maintenance and refurbishment. At the minimum, the roof fasteners should be inspected and any that are corroded, loose, or have lifted should be replaced. Replacement fasteners should be in a new hole to avoid rotten or stressed wood. This is more important for older houses, and houses in higher wind or corrosion zones.

For new houses, consider increasing the structural strength by going up to the next higher NZBC wind zone (BIA, 1992). The marginal cost of this may be low for many buildings. Bracing in the roof, fixing of roof material, and the connection of the roof to the walls are key areas. Greatly increasing the strength of only one area (for example, roofing fasteners) may be counterproductive, as it may only change the mode of failure (e.g. from roofing material lifting, to the loss of roofing material and battens), and in some cases could cause a more serious structural failure. Specialist design advice may be required.

Good opportunities for strengthening a house arise when re-roofing, re-cladding or lining, and re-piling. In some situations it may be required to bring the structure of a house up to modern standards when repairs or renovations or extensions are done. Consult the local territorial authority for advice on whether upgrading is required on renovation, or consult a builder or engineer to find out what options are available.

It is likely that buildings will leak during a tropical cyclone, due to a combination of high rainfall, near-horizontal rainfall, and high wind pressure around the house. Good attention to waterproofing and drainage detailing of all building elements, especially flashings, vents, and penetrations is advised.

5.3 Landslips

Landslips may be triggered by the heavy rainfall of tropical cyclones. However, at present there appears to be no method that could be used to anticipate the change in risk with climate change, and the most practical method available for dealing with landslips is to avoid potentially unstable areas. A precautionary approach to development in such areas is advised as any increase in tropical cyclone activity, or the increases in heavy rainfall expected with climate change, will make landslips more likely.

6. GREENHOUSE GAS EMISSIONS: HOUSES

The primary contribution of houses to climate change is the emission of GHGs during occupation. Most of these GHG emissions are from space heating and water heater appliances. Reducing these GHG emissions is important to help reduce New Zealand's overall GHG emissions (as is required by the Kyoto Protocol), and also to reduce the energy costs of buildings and improve comfort. Also, in the future, the cost and availability of energy may change, so by minimising the heating and GHG emissions, the exposure to this risk is reduced.

6.1 Assessment and decision

GHG emissions are assessed using the CCSI methodology for space and water heating in Section B.5.1, page 33, and Section B.5, page 33.

For space heating, any house with a rating less than 0 should be improved substantially. For water heating, any system with a rating of 0 or less should be upgraded or replaced when feasible with a better system. Cost effective improvements are recommended for all houses.

6.2 Generic houses

The most important non-occupant factors in heating use that are readily modified in an existing house are the insulation level, air infiltration rates, and fuel type and appliance, so these are the factors that are considered for the generic house types.

The insulation level and air-tightness of houses is influenced by the age of the house. For example, pre-1960s houses generally have wooden joinery, wooden strip floorboards, and were not insulated at construction. If they have not been modified, they are likely to be more draughty, and have a lower insulation value than, for example, post-1978 houses, which are predominantly fully insulated, and have more air-tight aluminium joinery.

Recommendations by generic house type:

1. Post-1978 modern house, fully insulated, aluminium joinery.
   Check airtightness of joinery and doors, and repair or replace seals. Check water cylinder, and if old and inefficient (Grade B or worse) insulate with cylinder wrap or replace with more efficient cylinder. Increase insulation in ceiling and floor

2. 1960-1978 modern house with aluminium joinery.
   Increase insulation in roof, walls[5], floor. Check water cylinder, and if old and inefficient (Grade B or worse) insulate with cylinder wrap and pipe insulation, or replace with a more efficient cylinder

3. 1960-1978 modern house with wooden joinery.
   As 2, and improve window and door seals

4. pre-1960 house.
   As 3. If wooden floorboards are exposed, seal and insulate underfloor space between joists

5. pre-1940 house
   As 4. If it has a fireplace, check for drafts or replace.

[5] Retrofitting insulation in walls is only really practicable when recladding or relining.

Adaptation Strategy For each house type, more ticks (✓) means higher priority	House Type 1 post-1978	2 1960-1978	3 1960-1978	4 pre-1960	5 pre-1940
Check airtightness of joinery and doors, and repair or replace seals, or weatherstrip	✓✓✓	✓✓	✓✓✓	✓✓	✓✓✓
Increase insulation in ceiling, floor and walls (in that order)	✓	✓✓✓	✓✓	✓✓✓	✓✓
Replace inefficient cylinders (less than A grade), and wrap cylinder and lag pipes	✓✓	✓✓	✓✓	✓✓	✓✓✓
Insulate and draughtproof wooden floorboards		✓	✓	✓✓	✓✓
Install damper, replace fireplace with firebox, or block				✓	✓✓

Table 4. Table of prioritised adaptations by house type

Open fireplaces are inefficient and draughty. Either install a damper and a modern firebox in the fireplace, or seal up the chimney and use another heat source.

6.3 Recommendations

For new houses in order of priority:

1. Use passive solar design principles (see Donn and Van Der Werff (1990) or EECA (2000))
2. Insulate in excess of the new NZBC H1 requirements, particularly to full cavity insulation in the walls
3. Install a solar water heater or heat pump
4. Choose mains gas over mains electricity for space and water heating
5. Choose an ‘A’ grade or better electric hot water system of sufficient size
6. Install energy efficient lights
7. Install double glazing.

The marginal cost of most of these options is very low. The more expensive options include installing a solar water heater or heat pump ($2-$5,000), or double glazing (around twice the cost of single glazing). These will give lower running costs, which vary with the climate, building type, and heating pattern.

For existing houses in order of priority:

1. Weatherstrip doors and windows against drafts
2. Seal unused chimneys and flues
3. Insulate the roof, floor and walls (in that priority) as much as possible
4. Insulate when re-piling, re-lining, or re-cladding if practical

5. When replacing water heaters, install a solar or heat pump water heater, switch to gas to reduce GHG emissions[6], or install an 'A' grade or better electric hot water system

6. Install a water cylinder wrap and insulate pipes

7. Install energy efficient lights.

The marginal cost of most of these items is low, especially if they are done as part of renovations.

There are many other benefits of the GHG reduction measures listed, besides reduced GHG emissions and energy costs. These could include: improved comfort; better temperature control; warmer, drier living spaces; better health; reduced asthma and respiratory illness; reduced overheating; and noise reduction. In particular, following passive solar design principles can reduce energy consumption, costs, and GHG emissions, but also give improved comfort in winter, and good protection from overheating.

More detailed information is available from EECA (The Energy Efficiency and Conservation Authority), PO Box 388, Wellington. Website www.eeca.govt.nz or BRANZ Bulletin 334: Reducing heat loss from existing houses. (BRANZ, 1995)

[6] By replacing with a gas system, the electricity demand on thermal power stations is reduced, which have higher GHG emissions per kWh of electricity than the direct use of the gas for water or space heating.

7. GREENHOUSE GAS EMISSIONS: OFFICE BUILDINGS

7.1 Assessment and decision

The assessment is performed using the GHG CCSI for office buildings in Section B.6 page 35. If the rating is less than or equal to 0 then some improvement is recommended. Cost effective measures are recommended for buildings that score 0 or above.

7.2 Design recommendations

Use specialist consultants to either design a building that does not require air-conditioning, or to design a building and HVAC system that is both energy efficient and of sufficient minimum capacity. Ensure that any air-conditioning system has low emission of GHGs, and has a proper management and maintenance system. Plant size and cost can, in some situations, be reduced by up to 75% through careful design, with similar reductions in operating cost.

Use specialist consultants to design an efficient, low energy lighting system. Big savings in running costs are possible, with similar initial cost, and also reductions in the cooling required. Aim for 9 W/m^2 or less.

Use specialist consultants to ensure that all other services (lifts, water pumps, security systems etc) are energy efficient.

Some general recommendations that may result in reduced GHG emissions nationally are to reduce energy use in general, to avoid air-conditioning, to switch from electricity to gas where possible, and to upgrade to energy efficient systems when refurbishing.

7.3 Retrofit recommendations

When refurbishing a building, there are many opportunities to reduce GHG emissions. For lighting, either replace the lighting system entirely with a high-efficiency system, or upgrade light fittings, controls, lamps, and ballasts with high-efficiency components. Air-conditioning systems should be replaced with high-efficiency systems, or reduced or eliminated by improvements in the thermal design (see design recommendations).

Opportunities also arise as part of regular maintenance. For lighting, replacing lamps and ballast when they fail may cost little or nothing extra, and give better lighting with lower running costs. Maintaining air-conditioning systems is crucial. When their refrigerants leak the energy consumption increases, and the refrigerants are often potent GHGs.

7.4 Maintenance recommendations

GHG emissions during maintenance and refurbishment account for about 20% of the total GHG emissions of office buildings in New Zealand. Extending the time between refurbishment cycles, and reusing materials and components could reduce this. Leakage of refrigerant from HVAC systems accounts for as much as 40% of the GHG emissions of air-conditioned buildings. Regular preventative maintenance, and replacement (with proper disposal) of poorly performing systems is recommended. See Camilleri and Jaques (2001) for a full discussion of these issues.

7.5 Synergistic effects

Reducing energy consumption in office buildings works synergistically to lower energy costs, lower peak internal temperatures, and reduce the load on (and perhaps the size of) air-conditioning systems. The temperature increases for modest levels of climate change of around 1°C can be offset by a reduction of only 10 W/m^2 in internal loads (see Section 3 above). Conversely, controlling overheating with solar gain control can lower energy consumption, by reducing the load on air-conditioning systems. Taking an integrated approach to the thermal design of office buildings can exploit these synergistic relationships.

Operating energy contributes around 30% of the GHG emissions of office buildings in New Zealand, (Camilleri and Jaques, 2001), compared to about 33% for the transportation of workers to and from the building. Choosing a site that is close to the workforce and readily accessible by public transport, and actively encouraging alternative transport could reduce this potentially large source of GHG emissions.

8. CONCLUSION

Assessment methods and adaptation strategies for both new and existing houses and offices buildings have been outlined for the climate change impacts of increased flooding, overheating, and tropical cyclones, and for reducing GHG emissions. Together, they form the basis for a decision support tool for adaptation to climate change. The assessment methods aid in deciding whether adaptation is needed, and the adaptation strategies provide recommendations on how to adapt.

This report forms the background information needed to prioritise policy and planning decisions around climate change impacts, and could form a resource base for other researchers, the building industry, or home-owners.

Adaptation or mitigation for climate change is generally cheapest, easiest, and most effective if done at the design or construction stage of a new building. Modifying existing buildings is generally more expensive and difficult, though there are still many cost-effective options available. A number of no-regrets options are found in the adaptation strategies, for example, exceeding minimum floor levels in flood hazard zones, or reducing lighting energy loads in office buildings.

The requirements of the NZBC are primarily concerned with health and safety issues and energy efficiency. Some of the impacts of climate change fall outside the current scope of the NZBC, either because they are not yet considered a health and safety issue (e.g. overheating), or that the current risk management approach does not yet include consideration of climate change impacts. In addition, since the lifespan of the building stock is so long, failure to upgrade the older stock to equal (or at least approach) current standards of strength, flood protection, and energy efficiency will increase New Zealand's exposure to the adverse impacts of climate change. It may be timely to introduce climate change risk management into the NZBC review process, especially in the areas of energy efficiency, overheating performance, flooding risks, and the requirements for upgrading older buildings to modern standards.

There are three major steps that could be taken to substantially reduce the vulnerability of new buildings to the impacts of climate change, and to reduce GHG emissions:

1. Utilise passive solar design principles

2. Reduce lighting loads to 9 W/m^2 or less, and minimise equipment loads in office buildings

3. Adopt a precautionary approach to development in floodplains and vulnerable coastal strips.

9. REFERENCES

Bonny, S., Reynolds, M., and Sims, C. New Zealand Houses Today - 1988. Weldon New Zealand. ISBN 0-86866-118-X

BRANZ. 1995. BRANZ Bulletin 334, June 1995. Reducing heat loss from existing houses. Building Research Association of New Zealand. Judgeford. Wellington.

Camilleri, M. J. 2000b. A draft climate change sustainability index (CCSI) for houses. BRANZ SR 95. Building Research Association of New Zealand. Judgeford. Wellington.

Camilleri, M. J., and R. A. Jaques. 2001. Implications of climate change for the construction sector: Office Buildings. BRANZ SR 96. Building Research Association of New Zealand. Judgeford, Wellington.

Carrad, L. New Zealand Home Builder: 80 New designs for homes and flats to suit all tastes. BRANZ Library catalog no 728.1 (931) CAR.

Donn, M., and Der Werff, I. V. 1990. Design guidelines: Passive solar in New Zealand. Report RD883. Ministry of Commerce. Wellington. ISBN 0114-8869.

EECA 2000. Passive solar design for New Zealand Homes. Energy-Wise Renewables - 11. May 2000. Energy Efficiency and Conservation Authority. Wellington.

Energy Group 2000. Adaptation and mitigation strategies for office buildings to minimize climate change impact. Energy Group Limited report no EGL-RR-06.

FEMA, 1993. Flood-resistant materials requirements. Technical Bulletin 2-93. Federal Emergency Management Agency (FEMA). United States Government agency.

Jaques, R. 2000. Summertime overheating in New Zealand house - influences, risks and mitigation strategies. BRANZ SR 89. The Building Research Association of New Zealand. Judgeford, Wellington.

Johnstone, I. M. 1995. The mortality of New Zealand housing stock. Architectural Science Review. Vol 37. pp 181-188.

Salmond, J. 1986. Old New Zealand Houses. Reed Methuen Publishers Ltd, Auckland. ISBN 0 474 00049 4.

Saville-Smith, K. 1999. Social aspects of Climate Change and office buildings. Centre for Research, Evaluation, and Social Assessment (CRESA). Wellington.

Watkins, L. 1995. New Zealand Home Collection. 1995-96. Edited by Leslis Watkins. ISSN 1172-6318.

APPENDIX A: HOUSING MORTALITY

Information about housing mortality has been drawn from several sources. Johnstone (1995) reports on the results of an extensive study of the mortality of the New Zealand housing stock. The BRANZ house condition survey (Clark, Page et al, 2000) provides information on the condition and age of houses, and some information on the demographics of house owners. Putterill and Bartlett (1980) provide information on the rehabilitation of dwellings, with insight into the socio-economic drivers.

Johnstone (1995) gives the useful economic life of a New Zealand house as ranging from 100-260 years, depending on several factors, including the annual expansion rate of the housing stock. At the historical average expansion rate of 1.7%, the economic life is 150 years. The BRANZ house condition survey noted that houses beyond the age of 60 years had an average condition independent of age, possibly due to renovations (Clark, Page et al, 2000). According to Johnstone (1995), many factors acting in combination "…will influence the future effective demand from additional households", including:

1. Age structure and increases in natural population
2. Levels of immigration
3. Housing stock occupancy and vacancy ratios
4. Mortgage interest rates
5. Household incomes
6. Affordability of housing
7. House prices
8. Government policy.

Continuous maintenance and renovations are required to ensure a long lifespan for New Zealand houses as they age, and the limits of this lifespan appear to be determined by factors other than the physical construction of the house.

In a report by Putterill and Bartlett (1980) it was concluded that rehabilitation activity was correlated with housing growth, household income, and household ownership, and that elderly people were less likely to rehabilitate aging housing stock.

In the BRANZ house condition survey, a weak link was identified between house condition and household characteristics. The houses in best condition were more likely to be owned by high income households, and older owners. The houses in worst condition were more likely to be occupied by younger households, with lower income, and larger mortgages. From this it seems reasonable to conclude that housing condition is related to disposable income.

Johnstone (1995) estimated that about 50% of New Zealand houses are lost by the age of 90 years, and that the economic lifespan of existing houses was 150 years. These figures varied with the expansion rate of the housing stock, from 89.3 years to 130 years for replacement rates of 2% and 0% respectively, while the average age of houses ranged from 32.6 years to 68.7 years.

Several future scenarios of housing demand and mortality were considered by Johnstone (1995), though none of these is a "forecast" of the future of New Zealand housing. A forecast of housing mortality is needed to assess which houses are likely to suffer the impacts of climate change, and to what extent.

In the absence of any credible forecast of the future mortality of the existing New Zealand housing stock, a simple approximation of the model of Johnstone (1995) is used. In this simplified model (based on a 2% replacement rate), all houses survive to 50 years, then 1% are lost each year, until at age 150 years, all houses are lost. For example, houses that are older than 50 years in the year 2000 will lose 1% of their year 2000 numbers each year.

The time-spans considered for the climate change studies were 2030 and 2070 for low and high impacts. Given a 50% survival rate at the age of 90 years, 50% of houses built during 1940 would be still usable in 2030, and 50% of those built in 1980 still usable by 2070.

The mortality statistics for each decadal cohort are given in Table A1. In 2030, 75% of the existing housing stock survives, and 33% by 2070. No houses built in the 1920s or earlier survive until 2070. The economic life of the surviving houses ranges from 10 years for the oldest houses, to 110 years for the 1990s houses.

From these figures, criteria for deciding whether mitigation for climate change impacts is necessary can be developed. For it to be worthwhile to adapt an existing house for an impact of climate change, the house should have a good chance of surviving until the impact occurs, the impact should be severe enough and persist long enough to justify the adaptation cost, and the house should have a worthwhile economic life afterwards. It appears to be difficult to assign a single cutoff criterion point that applies to all adaptations and all houses.

The following cutoffs are proposed to broadly satisfy these requirements, whilst not leaving more than about 50,000 houses from any decade exposed to climate change risk.

An arbitrarily imposed cutoff of 1950s and later houses for the 2070 period covers houses that have at least a 30% chance of surviving, and an economic life of at least 30 years. This covers 68% of the existing housing stock.

An arbitrarily imposed cutoff of 1920s and later houses for the 2030 period covers houses that have at least a 50% chance of surviving, and an economic life of 30 years. This covers 95% of the existing housing stock.

Adaptation and mitigation should be considered essential for newer houses, as they are likely to survive long enough to be affected, and may have a long economic life under climate change.

From the housing mortality forecasts above, it seems that most existing houses will suffer the adverse effects of climate change that occur by 2030.

Decade of construction	Chance of Surviving to 2030	% of stock in 2030	% Chance of Surviving to 2070	% of stock in 2070	% of present stock[7]
1890s	25%	0.3	0%	0.0	1.2
1900s	40%	1.4	0%	0.0	3.4
1910s	50%	2.7	0%	0.0	5.3
1920s	57%	5.4	0%	0.0	9.5
1930s	63%	3.0	13%	0.6	4.8
1940s	67%	5.1	22%	1.7	7.7
1950s	70%	12.0	30%	5.1	17.1
1960s	80%	16.6	40%	8.3	20.7
1970s	90%	14.0	50%	7.8	15.6
1980s	100%	8.8	60%	5.3	8.8
1990s	100%	5.9	70%	4.1	5.9
Totals		**75.1**		**32.9**	**100.0**

Table A1. Survival rates of existing housing stock based on a simplified mortality model

[7] Present stock breakdown percentages taken from the BRANZ house condition survey.

APPENDIX B: THE CLIMATE CHANGE SUSTAINABILITY INDEX (CCSI)

The Climate Change Sustainability Index (CCSI) is used to estimate the impact of climate change on a house or office building. The CCSI method is summarised here for ready reference. The draft CCSI appears in Camilleri (2000b) for houses and Camilleri and Jaques (2001) for office buildings. For each climate change impact a rating is given from –2 to 5, with –2 indicating a large impact, and 5 no impact. Note that some refinements have been made to the CCSI here.

B.1 Overheating: Houses

This CCSI method replaces the method described in Camilleri (2000b). The risk of overheating for a particular house is assessed using the following method, based on the results of Jaques (2000), using the solar window area to floor area ratio (SWR), with corrections for climate, insulation, and thermal mass.

The CCSI rating is done as follows:

1. Estimate Thermal Mass from Table B1

2. Estimate SWR

3. Estimate maximum summer temperatures using Figure 1

4. Modify for insulation, and climate from Table B2

5. Find CCSI rating from Table B3

Timber frame walls, concrete or timber floor:	**Mass Level**
Carpeted or timber floor	0
Partially Exposed Concrete floor	0.5
Fully Exposed Concrete floor	1.0
Concrete/Masonry internal Walls:	
Carpet, plaster walls	1.0
Carpet, Masonry walls	1.5
Exposed concrete floor, masonry walls	2.0

Table B1. Thermal mass levels for houses (adapted from Bassett, Bishop and Van de Werff (1990))

Estimate the SWR as the area of solar windows (unshaded north, west, and east facing) as a percentage of the floor area (Window area/Floor area x 100%). The area of solar windows is the area of windows from compass points southwest through north through east that are exposed to direct sunlight during the summer months. For unshaded windows this is equal to the glazing area. For shaded windows, some factor must be calculated or assumed. A shading calculation method is in EECA (1994b).

Use Figure 1 below to look up the likely maximum summer temperatures. To do this, find the solar window area ratio on the horizontal axis, go up to the line with the thermal mass level from above, then find the corresponding maximum temperature on the vertical axis. Once the maximum summer temperature is found, apply the following modifiers for insulation level and climate.

For insulation level:

- uninsulated: +1°C
  (most pre 1978 houses)

- insulated to approx level of NZS 4218:1996: +0°C
  (most post-1978 houses)

- insulated well in excess of NZS 4218:1996: -1°C
  (only superinsulated houses).

For climate location:

Location	Mean Maximum Summer Temperature (°C)	Modifier (°C)
Kaitaia, Whangarei, Taupo, Napier, Gisborne, Central Plateau	25	+4 °C
Auckland, Dargaville, Thames, Hamilton, Te Awamutu, Carterton, Blenheim, Cromwell	24	+3 °C
Warkworth, Tauranga, Christchurch	23	+2 °C
Whakatane, New Plymouth, Nelson, Queenstown	22	+1 °C
Palmerston Nth, Wellington, Dunedin	21	0 °C
Kaikoura	20	-1 °C
Hokitika	19	-2 °C
Invercargill	18	-3 °C

Table B2. Summer average maximum temperatures and modifiers

Modified Maximum Indoor Summer Temperature	CCSI Credits
< 19°C	5
≥ 20°C	4
≥ 21°C	5
≥ 22°C	2
≥ 23°C	1
≥ 25°C	0
≥ 27°C	-1
≥ 30°C	-2

Table B3. CCSI credits for overheating

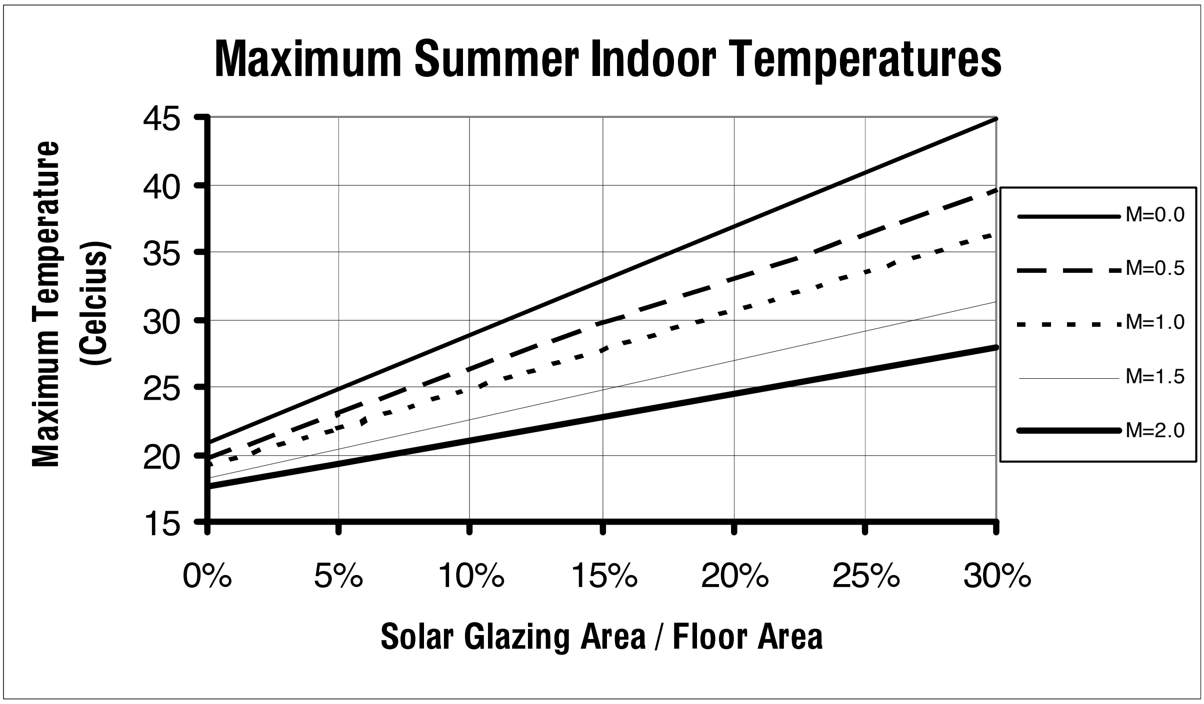

Figure 1. Maximum summer indoor temperature by solar glazing ratio and thermal mass level.

B.2 Overheating: Office buildings

The overheating rating attempts to rate how well the building will maintain comfortable temperatures with climate change. This rating scheme is not intended to promote air-conditioning as a sustainable means of controlling overheating. In the GHG rating section, air-conditioned buildings carry a heavy penalty because of increased energy use and refrigerant leakage, and will generally rate a -1 or -2.

To determine the CCSI rating, take the average maximum summer temperatures from Table B2, apply modifiers from Table B4 through Table B6, and then lookup the CCSI credits in Table B3. For air-conditioned buildings, then apply the credit modifiers in Table B7.

If reflective glass is used, calculate the effective window ratio by multiplying the window area ratio by the percentage reflectively of the glazing. For example, if 10 m^2 window glazing is 75% reflective, the effective window area is 10 $m^2 \times 75\% = 7.5$ m^2.

The modifiers for ventilation are the most difficult to estimate for a naturally ventilated building, because the ventilation rate is usually not known, and varies widely. If mechanical ventilation is used, the air exchange rate might be known or calculated, so use it. Otherwise openings on one side of the building will give about 3 ACH, and openings on both sides 10 ACH, provided that the size of the openings is of the order of a few square metres per 1000 m^3 of room volume. If there are no openable windows then the air change rate will be around 1 ACH.

Lighting Load (Watts/m²)	Temperature Modifier (°C)
< 25	+1
< 18	0
< 14	-0.5
< 9	-1
< 5	-1.5

Table B4. Modifiers for lighting load

Solar Window to Wall area percentage	Temperature Modifier (°C)
≤ 100	+2.5
< 90	+2
< 70	+1
< 50	0
< 30	-1
< 10	-2

Table B5. Modifiers for windows

Ventilation Rate (ACH)	Temperature Modifier (°C)
≤ 8	-1.4
≤ 5	0
≤ 3	+1
≤ 1.5	+2

Table B6. Modifiers for ventilation

	Credit Modifier
Fully Airconditioned	+4
Partly Airconditioned	+2

Table B7. Modifiers for Air-conditioning

Modified Temperature	CCSI Credits
< 19°C	3
≥ 19°C	2
≥ 20°C	1
≥ 21°C	0
≥ 23°C	-1
≥ 25°C	-2

Table B8. CCSI credits for overheating

B.3 Flooding

The CCSI for inland and coastal flooding are assessed separately, and then combined to give an overall flooding rating for the CCSI. The known actual flooding annual exceedence probababilite (AEP) is used to assign the CCSI credits. If the AEP is not available, an alternative method is used based on the flooding detectability criteria given in Camilleri (2000a).

B.3.1 Inland flooding

AEP	CCSI Credits
=0%	5
>0%	4
≥0.05%	3
≥0.1%	2
≥0.25%	1
≥0.5%	0
≥1%	-1
≥2%	-2
≥5%	X

Table B9. CCSI credits for inland flooding, based on AEP

The reference level is an AEP of 2% *after* the flooding risk has increased four-fold, i.e. a current AEP of 0.5%. The X rating denotes extreme risk, and a house with this rating is likely to be flooded more than once each decade with changes in flooding return period. The 5 rating only applies for houses with no flooding risk. No house on a floodplain, near a river, or in an urban area draining a large area qualifies. The flood risk here may be low, but is not 0.

Criteria	CCSI Credits
Never flooded, not on floodplain, not near river, lake, or natural drainage area	5
Never flooded, but in natural drainage area	4
Never flooded, but near river	3
Never flooded, but on floodplain	2
Never flooded, but nearby areas flooded	1
Never flooded, but adjacent properties flooded	0
Flooded once	-1
Flooded twice	-2
Flooded more than twice	X
Modifiers for flood record lengths	
Flood records longer than ~100 years	Add 1
Flood records less than ~25 years	Subtract 1
Flood records less than ~10 years	Subtract 2

Table B10. CCSI credits for inland flooding, based on site geography or flooding occurrence

B.3.2 Coastal flooding

If coastal flooding AEPs are known then these are used to assign CCSI credits on the same scale as for inland flooding (see Table B9). If they are not known use the criteria in Table B11, modified for the exposure of the coast.

Criteria **msl = mean sea level**	**CCSI Credits**
more than 20m above msl and more than 500m from shore	5
within 10m of msl and <500m from shore	4
within 6m of msl	3
within 5m of msl	2
within 4m of msl	1
within 3.5m of msl	0
Flooded once or within 3m of msl	-1
Flooded twice or within 2m of msl	-2
Flooded more than twice	X
Modifiers for flood record lengths	
Flood records longer than ~100 years	Add 1
Flood records less than ~25 years	Subtract 1
Flood records less than ~10 years	Subtract 2
Flooded more than twice	X

-1 for an exposed coast except if awarded 5 or -2 CCSI.

Table B11. CCSI credits for coastal flooding

B.3.3 Weighting coastal and inland flooding CCSI credits

The coastal and inland flooding credits are to be combined by taking the minimum value, with "X" for extreme considered the lowest value.

B.3.4 Office building flooding

Use the same method as for houses, taking floor levels into account using Table B12.

Building Feature	Credit Modifier
Timber Floor	-1
Floor at or below ground level[8]	-1
Equipment in basement[9]	-1

Table B12. CCSI credit modifiers for office building inland and coastal flooding

[8] Includes any water pathway, such as a driveway into a sunken car park or service entrance.
[9] Equipment such as telephone or computer networks, electrical switchboards, lift mechanisms, HVAC plant etc.

B.4 Tropical cyclones

Criteria by Region	CCSI Credits
Northland	-2
Thames/Coromandel, Bay of Plenty, East Cape	-1
Auckland	0
Central North Island	1
Lower North Island	2
Nelson, Marlborough	3
Canterbury	4
Westland, Fiordland, Southland	5

Table B13. CCSI credits for tropical cyclone risk

B.5 GHG Emissions: Houses

B.5.1 Space heating energy: houses

Method: Calculate the annual heating energy requirement for the house using the ALF 3 method (Stoecklein and Bassett, 1999), using the 7-9 am and 5-11 pm heating schedule, and 18°C temperature setpoint. Convert the heating energy consumption to kg CO_2 equivalent using the appropriate conversion factor for the house's heating appliances from Table B14, page 33. If there is a mixture of heating appliances then use the average emission factor. Divide by the assumed number of occupants, equals (number of bedrooms + 1) × 0.69, to arrive at the GHG emissions per person per year. Then convert to CCSI credits using , Table B15, page 33.

Fuel	**Heater Type**	**Fuel Emission Factor (kg CO_2 eq. /kWh)**	**Efficiency**	**kg CO_2 equivalent / kWh heating output**
Electricity	Air conditioner	0.64	1.9	0.34
Electricity	Ducted heat pump	0.64	1.68	0.38
Electricity	Resistance	0.64	1	0.64
Electricity	Floor	0.64	0.9	0.71
Electricity	Night store	0.64	0.8	0.8
Electricity	Ceiling	0.64	0.6	1.07
Natural gas	Unflued	0.19	0.81	0.23
Natural gas	Flued	0.19	0.8	0.24
Natural gas	Central heating	0.19	0.66	0.29
LPG	Unflued	0.22	0.81	0.23
LPG	Flued	0.22	0.8	0.24
LPG	Central heating	0.22	0.66	0.29
Diesel	Central heating	0.25	0.42	0.59
Coal	High eff. Double burner	0.36	0.8	0.44
Coal	Basic double burner	0.36	0.65	0.55
Coal	Pot belly	0.36	0.35	1.01
Coal	Free-standing metal fire	0.36	0.25	1.42
Coal	Open fire	0.36	0.15	2.37
Wood	Any type	Very low		

Table B14. Heating appliance efficiencies and greenhouse gas emissions (from Camilleri (2000a))

GHG Emissions (kg CO_2 per person per year)	CCSI Credits
0	5
0-150	4
150-350	3
350-750	2
750-1000	1
1000-1500	0
1500-2000	-1
2000+	-2

Table B15. CCSI credits for space heating GHG emissions

B.5.2 Hot water heating: Houses

The CCSI credits are based solely on the GHG emissions for the hot water heating appliance in the house. Lookup the CCSI credits for the hot water heater type in Table B16. Only solar water heating systems with no GHG emitting backup are awarded 5 CCSI credits.

Appliance Type	Efficiency	GHG Emission factor (kg CO_2/ kWh delivered heat)	CCSI Credits
Electric Night Store, Grade A	86%	0.74	0
Electric Heat pump	300%	0.21	4
Electric Solar	250%	0.26	3
Electric Instant	95%	0.67	0
Electric Boiler	90%	0.71	0
Electric Cylinder Grade A	86%	0.74	0
Electric Cylinder Grade B	82%	0.78	-1
Electric Cylinder Grade C	74%	0.86	-1
Electric Cylinder Grade D	70%	0.91	-2
Gas Solar	200%	0.09	4
Gas Condensing	80%	0.24	4
Gas Instant 5 star	66%	0.29	3
Gas Cylinder 4 star	58%	0.33	2
Gas Cylinder 3 star	55%	0.34	2
Gas Cylinder 2 star	51%	0.37	2
Gas Cylinder 1 star	46%	0.41	2
Coal Wetback	33%	1.08	-2
Fuel Oil Boiler	65%	0.38	2

Table B16. Efficiencies, and GHG emission factors for various water heaters (efficiency data from Roussouw (1997))

B.6 GHG Emissions: Office buildings

A highly simplified method of calculating GHG emission for office buildings is given here, based on either the calculated emissions for the actual energy used by the building, or on the climate, building type, and energy source.

B.6.1 Rating based on actual energy bills and energy source

GHG emissions can be estimated from actual energy bills using the following methodology

1. Obtain energy bills for electricity, gas, and other energy sources for an entire year

2. If not available for an entire year, take a set that includes an equal number of winter and summer months, and scale up by a factor 12/(no. of months)

3. Estimate GHG emissions using emission factors in Table B17

4. Assign CCSI Credits according to Table B18.

	Emission Factor kg CO_2 equivalent/kWh
Coal	0.36
Natural Gas	0.19
LPG	0.22
Diesel	0.25
Electricity	0.64

Table B17. Emission factors for major New Zealand fuel sources

GHG emissions kg CO_2 eq. /m²/yr	**Credits**
0	5
0-30	4
30-60	3
60-90	2
90-130	1
130-195	0
195-260	-1
260+	-2

Table B18. CCSI credit allocations for GHG emissions

B.6.2 Rating based on climate and building features

This highly simplified method ranks buildings in their likely order of GHG emissions. The reference level is a non-air-conditioned building in Wellington using electricity.

Start with the score for the energy source as in Table B19. "Mainly" means almost all energy is from that source. A mix is about a 50-50 split. Energy use refers to the whole building, including lighting.

Mainly Electricity	0
Electricity and Gas	+1
Mainly Gas	+2
Electricity and Renewables	+3
Gas and Renewables	+4
All renewables	Overall 5

Table B19. Credits modifier for energy source

Add the following modifiers for building type and climate zone from Table B20. The climate zones are from NZS 4243:1996.

Zone	Region	Base Credits Heating Only	Base Credits air-conditioned
Zone 1	Coromandel and Franklin districts and all districts north.	+1	-2
Zone 2	Remainder of North Island excluding Taupo, Ruapehu, and northern Rangitikei.	0	-1
Zone 3	All of the South Island and Taupo, Ruapehu, and northern Rangitikei districts.	-1	-2

Table B20. Regional base credits for heating only and air-conditioned buildings

REFERENCES TO APPENDICES

Bassett, M. R., Bishop, R. C. and Van de Werff, I. S. 1990. ALF Manual: Annual Loss Factor Design Manual. Building Research Association of New Zealand. Judgeford, Wellington.

Camilleri, M. J. 2000a. Implications of climate change for the construction sector: Houses. BRANZ SR 94. Building Research Association of New Zealand. Judgeford, Wellington.

Camilleri, M. J. 2000b. A draft climate change sustainability index (CCSI) for houses. BRANZ SR 95. Building Research Association of New Zealand. Judgeford. Wellington.

Camilleri, M. J., and Jaques, R. A. 2001. Implications of climate change for the construction sector: Office Buildings. BRANZ SR 96. Building Research Association of New Zealand. Judgeford, Wellington.

Clark, S. J., Page, I. C., Bennett, A. F., and Bishop, S. 2000. New Zealand house condition survey. BRANZ SR 91. Building Research Association of New Zealand. Judgeford, Wellington.

EECA, 1994b. Design for the Sun. Volume 2 Reference Manual. EECA. Wellington.

Jaques, R. 2000. Summertime overheating in New Zealand house - influences, risks and mitigation strategies. BRANZ SR 89. The Building Research Association of New Zealand. Judgeford, Wellington.

Johnstone, I. M. 1995. The mortality of New Zealand housing stock. Architectural Science Review. Vol 37. pp 181-188.

NZS 4218:1996. Energy Efficiency - Housing and small building envelope. Standards New Zealand. Wellington.

NZS 4243. 1996. Energy efficiency - large buildings. Standards New Zealand. Wellington.

Putterill, M.S. and Bartlett, P.J. Dwelling Rehabilitation in Auckland. National Housing Commission Research and Information Series Research Papter 80/14. Oct 1980.

Roussouw, P. A. 1997. New Zealand residential sector base case: End-use energy consumption. EERA. Wellington.

Stoecklein, A, and Bassett, M. 1999. ALF 3. Building Research Association of New Zealand. Judgeford, Wellington.