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Impacts of climate change on building performance in New Zealand

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Climate change is expected to impact on many aspects of building performance, with much of the existing and future building stock likely to be affected. Potential impacts of climate change on buildings are identified, evaluated as to how serious they might be, and actions are considered to ensure that future building performance is not compromised. Climate change scenarios for New Zealand defined the scale of climate changes considered for building performance. For each climate variable, relevant aspects of building performance were examined to determine if there is likely to be a significant impact. Where significant impacts were indicated, they were studied in detail and quantified where possible. A risk-profiling tool was formulated to cover the risk/severity of the most significant climate change impacts, which include flooding, tropical cyclones and overheating. Adaptation strategies were developed for each climate change impact, with different responses appropriate for each impact. Mitigation of greenhouse emissions is also addressed. For those risks where delaying action has serious consequences, it may be appropriate to consider changes in building or zoning regulations to anticipate the future impacts of climate change. Some implications for future building performance, design, standards and regulation are discussed.

Keywords: building performance, building stock, climate change, global warming, New Zealand, property, risk assessment, trends.

On peut s'attendre à ce que les changements aient des incidences sur de nombreux aspects des performances des bâtiments et que la majorité des bâtiments existants et futurs soit touchée. Cet article recense les conséquences potentielles des changements climatiques sur les bâtiments, les évalue quant à leur gravité et étudie les mesures à prendre pour que les performances des futurs bâtiments ne soient pas compromises. La Nouvelle-Zélande a étudié des scénarios de changements climatiques pour définir leur échelle en fonction des performances des bâtiments. Pour chaque variable climatique, on a examiné les aspects pertinents des performances des bâtiments afin de déterminer si elle est susceptible d'avoir un impact significatif. Lorsque c'est le cas, ces impacts ont été étudiés en détail et, dans la mesure du possible, quantifiés. On a conçu un outil de profil des risques pour couvrir les risques et la gravité des conséquences les plus importantes des changements climatiques, ce qui inclut les inondations, les cyclones tropicaux et les vagues de chaleur. Pour chaque conséquence des changements climatiques, on a formulé des stratégies d'adaptation, avec différentes réponses appropriées à chaque impact. On a également étudié l'atténuation des émissions de gaz à effet de serre. Quant aux risques pour lesquels tout retard dans les mesures à prendre aurait des conséquences sérieuses, il pourrait être judicieux d'envisager de modifier la réglementation concernant les bâtiments ou le zonage afin d'anticiper les conséquences futures des changements climatiques. Cet article traite également de certaines implications pour les futures performances des bâtiments, conceptions, normes et réglementations.

Mots clés : performances des bâtiments, parc de bâtiments, changements climatiques, réchauffement du globe, Nouvelle-Zélande, propriété, évaluation des risques, tendances.

Introduction

The world's climate is changing. The 1990s were the hottest decade since the 1860s, and the 1900s the warmest century of the millennium (WMO, 1999). Extreme weather phenomena and anomalies are also apparent, from temperatures 5°C higher than normal in many parts of Europe, to a super-cyclonic storm in India (WMO, 1999), to the melting of the ice-pack at the North Pole (Guardian Unlimited, 2000).

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International research has concluded that there is a discernible human influence on the climate (IPCC, 1996).

The likely impacts of climate change have been, and continue to be, explored by scientists in a wide range of disciplines (Watson *et al.*, 1996). It is clear that there may be many negative impacts on ecosystems and human systems caused by climate change and global warming. The implicit assumption that climate is static, bounded by known extremes and that it changes only slowly with time, is no longer tenable. Argument still persists about whether recent changes in climate have been influenced by anthropogenic greenhouse gas emissions, but this cannot alter the fact that the climate has changed significantly over the last century, and the best predictions available suggest that more changes are on the way. The risks of future climate change to buildings should be managed.

Building codes and practices around the world attempt to protect people and property from the normal range of climate variation. Once this normal range of variation is exceeded, then problems may be expected, ranging from uncomfortable internal environments to the wholesale destruction of large numbers of buildings. At some point, codes and practices must change to suit the new climate. However, changing codes and practices requires a good foundation of evidence and research to evaluate the likely implications, practicalities, costs and benefits – a requirement that is difficult to meet given the uncertainty of current climate change scenarios, and their long timescale.

Research background

The BRANZ (Building Research Association of New Zealand) climate change research programme was created in 1997 to fill a gap in the New Zealand climate change science base. Many assessments of the risks and impacts of climate change had been undertaken on selected New Zealand activities, for example the forestry and agriculture sectors, but there was only limited knowledge of the impacts of climate change on the construction sector. A New Zealand climate change impacts programme has existed since the early 1990s, but did not deal with impacts on buildings in any detail until this project began.

The goals of the research were:

- to identify and, if possible, quantify the impacts of climate change on houses and office buildings
- to develop an assessment tool to rate a building's vulnerability to the impacts of climate change
- to develop adaptation strategies for new and existing buildings

The research programme is now complete, and key results have been taken out to the building industry through industry publications, a BRANZ bulletin (BRANZ, 2001), and workshops for local and central government, to highlight the steps that could be taken to adapt and mitigate for climate change.

Climate change scenarios for New Zealand

A very brief summary of climate change scenarios for New Zealand is given in Table 1 for the years 2030 and 2070. Detailed climate change scenarios developed by the National Institute for Water and Atmospheric Research (NIWA) are given in Camilleri (2000a).

Impacts on buildings

Even the quantifiable climate changes listed in Table 1 could be expected to influence almost every aspect of construction practice and building performance. The challenge in assessing the impact of climate change on buildings is to decide which impacts are significant enough to justify changing building practice, or increasing the protection of buildings.

For each climate factor in Table 1, an analysis of the sensitivity of the related building performance was undertaken. The following direct and indirect impacts on buildings were identified and assessed:

- decreased winter space heating
- decreased water heating energy

Table 1 Summary of climate change scenarios for New Zealand

Climate variable	Year 2030	Year 2070
Temperature	+0.3 to +0.9°C	+0.6 to +2.7°C
Sea level rise	4–24 cm	10–60 cm
Extreme rainfall	No change to a doubling of the AEP[1]	No change to fourfold AEP
Annual rainfall	–5 to +10% by region	–15 to +30%
UV	decrease by 6–7%	decrease by 10%
Solar radiation	Unknown	Unknown
Wind speed and direction	Unknown	Unknown
El Niño southern oscillation	Unknown	Unknown
Tropical cyclones	Unknown	Unknown

- increased overheating and air-conditioning load
- greenhouse gas (GHG) emissions of houses
- increased costs due to carbon or GHG charges
- changes in electricity costs
- increased inland flooding
- increased coastal flooding, erosion, and rising water tables
- degradation of polymers
- changes in wind
- increased tropical cyclones
- increased insurance costs
- changes in timber properties

As the number of potential impacts on buildings is large, this paper examines only a selected few to briefly illustrate the most significant impacts, and provide examples of the four possible outcomes of the assessment process:

(1) The impact on buildings is quantified, and shown to be significant

(2) The impact on buildings is quantified, and shown to be insignificant

(3) The impact on buildings is not well quantified, but shown to be insignificant[2]

(4) The impact on buildings is not well quantified, but cannot be shown to be insignificant

Decreased winter space heating for houses with increased temperatures is an impact of type (1) (quantified/significant), since the climate change scenario is good, and simulation methods are available to quantify the large decreases in heating demand. Adaptation of houses for this impact is more about maximizing the opportunity of lowering energy requirements and CO_2 emissions than avoiding adverse effects. With increasing temperatures, it becomes easier to design and build houses that need little or no space heating. However, unless this is done when houses are first built, sub-optimal performance may be built in for the 50–150 year life of the house.

To quantify the reductions in heating energy, heating simulations of houses were performed using the Annual Loss Factor (ALF) method (Bassett *et al.*, 1990).[3] The anticipated percentage reductions in space heating for several locations in New Zealand are given in Table 2. The range for each location (representing a major climate region) and year reflects the possible range of temperature changes given in Table 1. The percentage reductions in heating energy were found to be similar regardless of insulation level, orientation, thermal mass level, heating schedule or thermostat temperature.

Table 2 Space heating energy reductions with climate change

Location	Latitude	2030	2070
Auckland	36° 51′ S	12–70%	69–79%
Wellington	41° 16′ S	25–33%	29–86%
Christchurch	43° 32′ S	4–14%	9–62%
Invercargill	46° 25′ S	12–19%	15–51%

Decreased water heating energy is an impact of type (2) (quantified/insignificant) as, although it can be quantified, the energy consequences are relatively minor and no action is required.

Reductions in the required hot water heating energy of ~3% per 1°C increase in temperature are expected as a result of the warmer air temperature on the cold water supply temperature (Camilleri, 2000a). The temperature increases given in Table 1 would result in water heating energy decreases of 0.8–2.8% by 2030, and 1.8–8% by 2070, which are insignificant, except for the most extreme temperature increase.

Changes in non-cyclonic wind speeds are an impact of type (3) (not quantified/insignificant) as the climate change scenario is non-existent, but methods are available to show that the impacts on buildings are likely to be undetectable. Note that wind damage from tropical cyclones is considered separately.

Extreme wind causes damage to houses, especially to roofs and windows, and damage to services such as power and telephone lines. New Zealand timber-framed houses already have their structural design dictated by wind zones (NZS 3604, 1999). The risk is that, with climate change, the wind zones and wind exposure could change, possibly exposing houses to stronger winds more frequently than is acceptable according to the current New Zealand Building Code requirements.[4]

Currently, there is no reliable assessment of the possible changes in wind speeds with climate change. In the absence of a climate change wind scenario, a sensitivity study to changes in wind speed was carried out. This considered the problem of detecting a change in the frequency of extreme winds. It was found that any likely change in the frequency of extreme wind speed would be statistically undetectable over a 50-year time period, even if the current design wind speeds were known precisely. If the estimated error in current design wind speeds is considered, then there is no practical way of detecting an increase in design wind speeds based on meteorological data, or a wind data proxy such as building damage statistics. From this, it was concluded that even if climate change led to large increases in the AEP for damaging winds, these changes would be undetectable over a 50–100 year (or longer) time span. Therefore, there is no need to change design wind speeds.

Degradation of organic polymers is an impact of type (3) (not quantified/insignificant) as this depends on many different climate change scenarios including temperature, UV, rainfall and humidity, some of which are non-existent. However, the timescale in which any impacts would become apparent is greater than the lifespan of most organic polymers used in buildings. Most organic polymer materials in current use are expected to be replaced well before they might be affected by climate change, so there is no need to adapt buildings now or in the near future. This is a potential problem that requires no adaptation of the current building stock.

Tropical cyclones are an impact of type (4) (not quantified/not insignificant) as the climate change scenario is very uncertain, and the possibility of marked adverse impacts cannot be discounted.

Climate change science currently has several conflicting assessments of changes in tropical cyclones in the New Zealand region, ranging from no change to slight increases in frequency and intensity. When cyclones do strike New Zealand they result in substantial damage. Insurance claims resulting from cyclones from 1978–88 amounted to ~$55 million, with more than $50 million in 1988 from Cyclone Bola alone (Insurance Council, 1997).[5] Any increase in the number of tropical cyclones would dramatically increase weather-related damage, including structural damage from wind, increased flooding, and increased land-slips. The potential for damage to houses from any increase in tropical cyclones is so large that, despite the uncertainties, this potential impact must be taken very seriously.

Climate Change Sustainability Index

The Climate Change Sustainability Index (CCSI) is a tool created to aid the assessment of the impact of climate change on a building (Camilleri, 2000b). It is designed to rate the impacts of the most significant impacts of climate change (impact types (1) and (4)) so that potentially vulnerable buildings can be identified, and if possible remedial action identified. The assessment methodology is built around industry standard tools, and readily available information.

The complete CCSI consists of two separate numerical ratings: one for impacts on a house (which includes summer overheating, coastal and inland flooding, tropical cyclone

Figure 1 Rural flooding in New Zealand (photo courtesy of BRANZ)

Figure 2 Roof damage caused by high winds in New Zealand (photo courtesy of BRANZ)

Figure 3 Building damage caused by a landslip triggered by stormwater in an urban area (photo courtesy of BRANZ)

risk), and another for greenhouse gas emissions for space and hot water heating (not discussed in this paper).

The rating for each impact is on a scale of −2 to +5, with 0 being the reference level for normal building performance, and an 'X' rating being available for an extreme risk. This rating scale was adapted from the Green Building Assessment Tool (GBTool) (Larsson, 1998).

The CCSI rating is designed to be easy to apply using limited data. For some impacts, a comprehensive method is used if data is available, and a simplified method is used if no data is available. The CCSI for inland flooding is provided as an example.

Inland flooding – CCSI

The CCSI rating for inland flooding has both a comprehensive and simplified method.

The comprehensive rating (Table 3) is based on known flooding risks. The rating of zero is for an Annual Exceedence Probability (AEP) of 0.5% under current climate conditions. The 'X' rating denotes extreme risk, and a house with this rating is likely to be flooded more than once each decade if the flooding risk increases with climate change. 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 would qualify. The flood risk here may be low, but is not zero.

The simplified rating (Table 4) is based on the site geography and local knowledge of flooding occurrence. For many parts of New Zealand prone to flooding, the actual risk of flooding either under current or future climate is not known, because of factors including a lack of monitoring, changes in the catchment or relatively recent development.

Adaptation strategies

The CCSI has been extended to include adaptation strategies aimed at reducing the potential impact of climate change on buildings, and the greenhouse gas emissions of buildings. Together, they form the informational basis of a decision support tool to aid in planning and adaptation for climate change. A BRANZ Bulletin summarizing the findings and recommendations has recently been published, and distributed to more than 12 000 construction professionals (BRANZ, 2001).

Once the CCSI rating is performed, a decision can be made as to whether or not adaptation for climate change is necessary. CCSI ratings of 0 or 1 or lower (depending on the impact) would justify adaptation in terms of building performance. Once the adaptation is deemed necessary, a range of basic options are presented, depending on the impact, severity, the type of building, cost, practicality, etc. Other issues are also important, such as the timing of adaptation (adapt now or in the future) and the economic value and life of the building.

Table 3 Comprehensive CCSI credits for inland flooding, based on current AEP

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

By creating a set of adaptation strategies, the core problems of adaptation to climate change are highlighted.

The adaptations range from easy and cheap, to costly and difficult. Actions taken at the design and build stage are generally much cheaper than during the maintenance or refurbishment periods, and some options are only practicable for a new building. This disparity in costs provides a compelling argument for adopting the ‘no-regrets’ adaptation and mitigation measures into all new buildings, and promoting the low cost options that provide immediate benefits. Examples of the former might include higher floor levels on suspended timber floor houses, and for the latter, higher levels of insulation in houses, or energy efficient lighting in office buildings. Similar cost economies can occur for existing buildings during refurbishment and replacement, for example retrofitting insulation in walls when re-lining or re-cladding, raising floor levels when re-piling, or upgrading to high efficiency water or space heating when replacing. There are currently no requirements in the New Zealand Building Code to upgrade existing buildings, except in special circumstances.

Note that the need for adaptation for houses varies with the age of the building, as older houses are predicted to be more likely to be demolished and replaced before climate change impacts occur. Therefore, recommendations from the research were:

Table 4 Simplified CCSI credits for inland flooding, based on site geography or flooding occurrence

Criteria	CCSI credits
Never flooded, not on floodplain, not near river, lake, or urban drainage area	5
Never flooded, but in urban 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

- houses built before the 1920s do not need to be adapted
- houses built between 1920–49 should be adapted for the moderate levels of climate change for 2030
- houses built in the 1950s and later should be adapted for the more extreme climate change of 2070

Inland flooding – adaptation

Continuing with the example of inland flooding for housing, there are a number of options for reducing the risk and impact of flooding, including:

- do not build on a flood-prone site
- exceed minimum above-ground floor levels
- consider multi-storey construction
- use flood-resistant materials and design
- install essential, vulnerable equipment as high above ground level as practicable

Taking steps to reduce the flooding risk is most effective before construction of a new house. The marginal cost of higher floor levels or flood-resistant materials is likely to be low at this stage. For existing houses, adaptation to an increased flooding risk is likely to be more difficult and expensive. Some measures to consider for existing houses include:

- raise or move house[6]
- build a second storey and use first storey (ground floor) as non-habitable space
- replace cladding, flooring, and linings with flood-resistant materials
- move services (hot water, electricity distribution board) to above flood levels
- build levy or floodwall around the house
- upgrade existing flood defences
- build large-scale flood defences

Unfortunately, adaptation can be expensive and difficult, and may force changes in land use practices, such as restrictions in coastal zones. As the impacts are not likely to occur for many decades, and the benefits of adaptation may not be apparent until flooding occurs, it may be difficult to get support from the community. This may mean that the cheapest and most effective adaptations, which are land use restriction and minimum floor levels, may not be used, forcing either costlier options later, or the full consequences of increased flooding damage. Delaying action may be very costly in this situation.

In New Zealand, flooding insurance is automatically included in most household insurance, and may be obtained by businesses and farmers. Cover may be expensive or refused in some particularly flood-prone areas. Some recent severe flooding events, including three massive floods within 5 years that would have been expected only over 200 years, have prompted the New Zealand insurance industry to take a more active role in resource management. However, at this stage, insurance cover has not been withdrawn nor insurance premiums increased, although some properties were condemned by local authorities. It is important that the insurance industry maintains and reviews insurance premiums at appropriate levels, as rising premiums for flooding risk give an impetus for property owners and local government to actively manage the risk to reduce premiums and maintain cover. Failure to do so could result in a sudden increase in premiums, or withdrawal of cover, which may be disastrous for communities and individuals, as without insurance cover financial support from lending institutions may be withdrawn, and property values drop, further limiting the financial resources of the community.

The last option of building new large-scale flood defences seems to be the least likely, unless a major policy shift occurs in New Zealand. Very few such defences have been constructed in New Zealand recently, and there is currently no nationwide body or funding organization that co-ordinates the construction and maintenance of flood defences. Such defences are funded, built, and maintained by local and regional government, paid for by locally imposed taxes. It seems unlikely that local and regional government could find the resources or have the support of the local community to raise the necessary funding for the, as yet, poorly understood future risk of flooding due to climate change.

Mitigation strategies

The mitigation of GHG emissions is also addressed in the CCSI, by rating the GHG emissions of houses and office buildings, and providing information on how to reduce them. It is important that adaptation strategies for climate change do not lead to increased GHG emissions, which would work against the mitigation strategies.

Adaptation for overheating is one impact where this may occur. The effect on energy use of increased temperatures and adaptation to overheating in New Zealand is complex. The following examples highlight some of the issues.

In houses, increased temperatures reduce the energy needed to maintain a given heating schedule. However, if people change their behaviour and want increased comfort, much of the energy saving potential may be lost.[7] If people decide to add air-conditioning to control overheating, then energy use would increase markedly.[8] Improved thermal design with higher insulation levels, better solar gain control, ventilation and double glazing could all control overheating, and give improved comfort with less energy use.

In office buildings, increased temperatures may cause an increase, decrease, or no change in energy use, depending on the building type and location. For air-conditioned buildings, increased temperatures increase energy use in warm climate zones like Auckland, and cause almost no change in cool climate zones like Christchurch. For unconditioned buildings, increased temperatures reduce energy use in all cases, unless air-conditioning is added to control overheating, which would increase GHG emissions dramatically. Overheating control measures include solar gain control, reduction of internal loads, enhanced ventilation, and insulation of un-insulated buildings,[9] and these reduce energy use in almost all cases for both air-conditioned and non-air-conditioned buildings.

Improving the thermal performance of buildings can work synergistically to achieve both the adaptation to increased temperatures and the mitigation of GHG emissions. If this is not done, then the increased use of air-conditioning could lead to large increases in GHG emissions.

Implications for the future

The research has shown that climate change will have different impacts on different buildings depending on the building type, scale, use, construction and location. The different climate impacts call for different actions and responses, as discussed in the section on adaptation strategies, which focused on changes in design and construction practice. There is also scope at policy level for revising existing standards, and changing or creating building controls to maintain current levels of building performance with likely changes in the climate due to climate change.

The New Zealand Building Code (NZBC) is a performance-based code, which regulates only those matters essential for ensuring that buildings are safe and sanitary and have means of escape from fire, disabled access, and the efficient use of energy. It does not deal with aesthetics, comfort or the owner's specific interests. The development of code requirements must pay due regard to the 'national costs and benefits of any control, including (but not by way of limitation) safety, health, and environmental costs and benefits' (Building Act 1991, Part II, Section 6).

Thus, only those impacts of climate change that can be shown to fall specifically within the ambit of the NZBC can be considered for regulatory control. These have included embodied energy and carbon emissions, which were considered in the 1996 revision of NZBC Clause H1: Energy Efficiency, but not incorporated due to the lack of data and suitable implementation mechanisms (Isaacs *et al.*, 1996).

A high requirement for proof of change in the climate may lead to a failure to incorporate issues such as listed in Table 1. In this section, some options for each of the climate change impacts on buildings are investigated.

Overheating

Control or prevention of overheating in houses and commercial buildings is not included in the NZBC. It appears unlikely that it will become part of the NZBC in the near future, as overheating is currently not perceived as either a health or safety issue. This attitude could change if overheating occurred in large numbers of buildings for significant periods of time. Even if overheating were included in the NZBC, it is technically complex and difficult to assess, as there are so many interactions between building components, form, climate and behaviour. Simplified measures, such as placing restrictions on window areas or prescribing shading or window treatment, might well be rejected by the design and construction sectors as being too restrictive and prescriptive, as they currently enjoy an almost unlimited reign in the form and aesthetics of their buildings. At the extremes, anything from a windowless box, to a building with roof and walls made entirely of glass can (with sufficient care) be made to comply with the NZBC.

Best practice guides could provide a good informational base to influence the design of buildings, rather than regulatory requirements.

For office buildings, a reduction in overheating of ~1°C can be achieved by reducing internal loads (lighting and/or equipment) by ~10 W/m^2 (Energy Group, 2000), compared to the NZBC requirement of 18W/m^2 (NZS 4243, 1996). This is technically feasible and cost-effective now for lighting loads. It would ensure that the future overheating performance of office buildings for modest temperature increases will not be any worse than today.

Flooding

Protection from flooding for housing, communal residential (e.g. hotels) and communal non- residential (e.g. churches) buildings is included in the NZBC. The current performance requirement under NZBC Clause E1: Surface Water is that the AEP for over-the-floor flooding must not exceed 2% (BIA, 1991). However, the assessment of the flood risk assessment, as set out in the Verification Method (E1/VM1), need only take account of the historical characteristics of the total catchment as well as the particular building site (BIA, 1992). It does not need to consider any potential future climate changes.

The assessment of flooding under climate change is that flooding AEPs could increase by as much as two to four times, which indicates that some buildings built under today's Building Code may have a future flooding risk that is currently considered unacceptable.

Should the Verification Method be revised, to require a lower current risk of flooding to act as a 'buffer' for any future climate change? Climate change scenarios for extreme rainfall and flooding in New Zealand do not yet provide a regional breakdown, which if available could be used to develop a targeted response. As it will be very costly to adapt houses in the future for an increased flooding risk, it seems sensible to use reasonable, inexpensive, 'no regrets' options such as tighter land use controls and higher minimum floor levels.

There are no limits on flooding risk for commercial buildings in the NZBC. The management of the flooding risk is left either to local or regional government under their zoning regulations, or to building owners to incorporate active (e.g. pumps) or passive (e.g. flood design) responses.

Local and regional government has a strong influence over zoning and district plans, and could adjust the flood risk zones to anticipate future risks. However, the possibility exists for property owners to challenge these changes through legal appeals.

Tropical cyclones

The risk of increased tropical cyclone activity is uncertain with climate change, but the impacts include damage from wind, inland flooding, and coastal flooding. As all these three risks are concurrent, and widespread, the potential for disaster is high.

Without any scientific certainty about the future risks, it is difficult to factor this risk into decision making. At the very least, the inland and coastal flooding risks should be reviewed as for the known increased flooding risk from increased rainfall, and perhaps some extra margin given for the likely coincident coastal and inland flooding with cyclones.

Future directions

The first round of technical assessments of climate change impacts is complete, and may soon be updated for the most recent IPCC climate change scenarios. The research team decided that further research on technical assessments at this time would not lead to greatly improved impact statements, and therefore would not aid the adaptation process.

A major part of the research effort went into exploring how people perceive climate change risks, and how particular groups could be influenced to respond to these risks (Saville-Smith, 1998; 1999). Governments (local, regional and national) were found to be the most responsive groups, and a seminar series has recently been completed to highlight how they might be affected, and to provide them with the information they need to begin the adaptation process. The construction industry and the public were found generally to be unlikely to take early action to respond to climate change risks. Consequently, both the construction industry and the public have been targeted with information in the form of the BRANZ Bulletin (BRANZ, 2001), articles in trade magazines, and press releases to try to raise their awareness. These responses will continue, with the promotion of the CCSI and adaptation strategies as the main strategy for the near future. Groups such as the insurance industry, commercial building investors, public housing, and regulators may also be specifically targeted.

Conclusions

It is clear that, even without the current uncertainties in climate change science and the potential impacts of climate change on buildings, establishing suitable mechanisms to deal with these issues is problematic.

The long lifespan of the building stock is perhaps the most problematic issue, since most buildings built now will still be in use in 50–100 years time, but the most effective time for adaptation is before these buildings are constructed. Consequently, it is crucial to develop policy and strategies now that reduce long term risks for new building stock, encourage early adaptation where practicable for existing building stock, and at the very least take a precautionary approach to the uncertain risks of climate change.

Building owners seldom make direct decisions about the exposure of their buildings to risk – these decisions are usually made by local authorities, or by default by adherence to building codes and standards. Whilst the insurer is able to abandon a building by withdrawing cover if climate change impacts are severe, building owners may find their position untenable. Once insurance cover is withdrawn, lending finance and resale become difficult and property values drop. Insurance alone cannot be relied upon to protect building owners from the most severe impacts of climate change.

As a result of climate change, the future performance of buildings may be significantly different than current performance for:

- coastal and inland flooding
- overheating (as defined by occupant expectations)
- wind damage and flooding associated with tropical cyclones

The CCSI gives an assessment of the vulnerability of buildings to these climate change risks. The adaptation strategies outline some ways that buildings can be changed so that current building performance standards are maintained. The appropriate response depends on the particular impact, but can range from late action by building owners, or early action through building controls or good practice standards.

For flooding and tropical cyclone risks, a 'wait and see' approach is likely to increase both the costs of adaptation, and the amount of damage caused to buildings. Early action, in contrast, will generate an effective, and ultimately lowest cost, response.

Climate change risks should be included in future reviews of the appropriate clauses of the NZBC and associated Approved Documents. The scope, time scale, and uncertainties around climate change risks may be outside the current scope for such reviews, as may be the process by which such risks are assessed and managed. It is assumed in the NZBC that buildings will have a minimum life of 50 years, and it is likely the climate will have changed within that period. Given the increasing certainty of the likely type of climate change to occur in the coming century, regardless of the cause, the need for consideration in the NZBC is becoming clear. It is possible that other land-use legislation may also need to consider issues of changing climate, but this is outside the scope of this paper.

The impacts of climate change are never going to be precisely known, and will form only one part of any risk management process. The likely improvements in climate change scenarios and impact assessments in the near future will not fundamentally change the way these risk management processes operate. If the scope of the risk management excludes or heavily discounts the risks of this nature, then buildings and society are likely to suffer potentially costly and dangerous consequences. Full protection from potential climate change impacts could be very costly, and politically difficult. However, if some reasonable, cost-effective, precautionary measures are taken in the near future, then many buildings could be protected from some of the likely impacts of climate change.

Research on climate change mechanisms and impact statements must continue, as their current uncertainty is a major impediment to adaptation. However, given their slow progress and the need for early action in the construction sector, it is important that the lengthy adaptation process begin now. The construction industry and the public should be shown how adaptation can give worthwhile immediate and short term benefits in both performance and costs. If people demanded 'best practice' instead of the 'barely legal', defined by building codes and standards, then climate change impacts would be reduced.

Linking 'best practice' standards and quality labelling of buildings to sale and resale, tenancy, maintenance costs, lending finance, and insurance costs could change this mentality and also stimulate early adaptation.

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Endnotes

[1]AEP is the Annual Exceedence Probability, which is defined as the probability that a pre-defined threshold will be exceeded in any one year. For example, there may be a 10% AEP for a rainfall rate of 100 mm/hour or more for a duration of 10 minutes.

[2]For example, when the change in climate variable alone is insignificant, or when other considerations make any conceivable impact insignificant.

[3]The Annual Loss Factor (ALF) method is a thermal design aid for buildings that allows rapid and easy calculation of the space heating needs of New Zealand houses, and the demonstration of compliance with the energy performance standards of the Building Code. It is used as either paper-based worksheets or a computer package. The ALF method works by calculating the heat loss of the building thermal envelope as the sum of the heat losses of each building element, where the heat loss of each building element is calculated as surface area multiplied by U-value multiplied by an annual loss factor. The annual loss factor is a modifier based on factors such as the local season degree days, orientation of building element, heating schedule, etc.

[4]The ultimate limit state wind speeds for New Zealand are currently at approximately the 1 in 350–500 return period, and the serviceability limit state at the 1 in 20 year return period (NZS 4203, 1992).

[5]$50 million dollars is a large sum for a single weather related event in New Zealand, as there are only ~1.3 million houses and a population of ~4 million people.

[6]Most houses in New Zealand are of timber frame construction, on pile foundations, and can be readily raised or relocated, although at some expense.

[7]Most New Zealand houses do not have central heating and are heated intermittently in a few rooms, for example, the living room only during the evening. Typical heating temperatures are 18–20°C.

[8]Only ~2% of New Zealand houses have air-conditioning.

[9]Note that in New Zealand's temperate climate, insulation much in excess of the minimum requirements of the New Zealand Building Code may increase overall energy use for some office buildings.