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Implications of Climate Change for the Construction Sector: Office Buildings

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Preface

This is the third report in a series prepared during research into the implications of climate change for the construction sector. This report deals with climate change impacts on office buildings, extending the research of the first report on Houses (Camilleri, 2000a). Many aspects of climate change for office buildings are similar to those for houses, so to avoid duplication, the reader is referred to the first report for details of climate change scenarios and impacts on houses.

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IMPLICATIONS OF CLIMATE CHANGE FOR THE CONSTRUCTION SECTOR: OFFICE BUILDINGS

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ABSTRACT

The built environment will be affected by climate change in many ways. The first reports in this series identified the impacts on New Zealand houses, and introduced a Climate Change Sustainability Index (CCSI). This report extends that research to cover office buildings, and adapt the CCSI. Climate change impacts on office buildings are similar to those for houses for many climate change factors, with the exception of: damage from flooding; stormwater flooding; overheating; heating; and life-cycle Greenhouse Gas emissions.

Office buildings may be more susceptible to climate change induced flooding damage than houses. Detecting changes in flooding incidence for office buildings in highly urbanised areas is expected to be more difficult than for houses, as the drainage characteristics of the cityscape have changed much historically, and will continue to change in the future.

Studies of heating and cooling for office buildings have highlighted different effects/impacts for buildings with or without air-conditioning. Air-conditioned buildings are least susceptible to climate Change, as any likely change in temperatures can be controlled by existing or replacement plant. Naturally ventilated buildings will suffer from overheating more often, perhaps forcing design changes or the installation of air-conditioning.

Energy use and Greenhouse Gas (GHG) emissions will change. For air-conditioned offices in Auckland, energy use increases with increasing temperatures, whilst in Christchurch, energy use decreases for small temperatures increases, and then increases. For the naturally ventilated buildings modelled in Auckland and Christchurch, overall energy use decreases, and the percentage of uncomfortable hours increases, to up to 50% of all occupied hours at the extreme. Increasing discomfort could lead to the installation of air-conditioning in these buildings.

The life-cycle GHG emissions of office buildings have been studied in brief, to find estimates of yearly GHG emissions for various building phases. In order from largest to smallest they are: transport of office workers, operating energy, refurbishment, initial manufacture, and leakage of CFC and HCFC from HVAC systems. This HVAC leakage is alarming, as it is comparable to the initial emissions, and the issue appears to be largely ignored by building managers and occupants. Air-conditioned buildings have about 75% higher GHG emissions than unconditioned buildings, and their largest single GHG emission could be HVAC leakage. No one phase dominates for office buildings, so any strategy for reducing the overall GHG emissions for office buildings should address all phases.

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1. INTRODUCTION

The first report in the series (Camilleri, 2000a) examined the implications of climate change for Houses in New Zealand. This report extends that research to cover office buildings. The response of office buildings to climate change is expected to be similar for many aspects of climate change, and this report focuses on the differences between houses and office buildings.

2. SCENARIOS

The scenarios of climate change for New Zealand are the same as in Camilleri (2000a), as there have been no significant changes to date. They are not duplicated in this report, so it is necessary to refer to section 2 in Camilleri (2000a) for summaries of the scenarios, and to section 18 for the detailed scenarios.

3. OFFICE BUILDINGS CLIMATE CHANGE ISSUES

The general idea is to explore the differences between houses and office buildings, and try to identify the differences that may lead to a different response to climate change. It is assumed that the effects of climate change on office buildings will be identical to the effects on houses, unless there are important differences between office buildings and houses (e.g. shape, size, patterns of use, construction).

3.1 Methodology

The basis of the method is to assume that where office buildings are similar in, for instance, structure, performance, or user behaviour, to houses with respect to a particular climate change impact, the impacts will be similar. Therefore, the focus is on identifying how offices are different from houses, and if these differences are likely to lead to a different response to climate change. For each climate change issue identified in Camilleri (2000a), the design and performance of office buildings is compared to that of houses to determine if the climate change impact may be different. If it is different, then the impact will be quantified.

3.2 What is an Office Building?

The definition of building types by Statistics New Zealand (1998b) focuses on building use, rather than building form. The Commercial Buildings class includes office or administrative buildings, banks, retail outlets, restaurant or other food service, and entertainment buildings.

Office and administrative buildings are the building type considered for this research. For the purposes of the research, an office building is defined as any building where the building was purpose–built for office and administrative type work. This definition will include many building forms, including high-, medium-, and low-rise buildings. The high-rise buildings are most different from houses, both in terms of their construction and fittings. Low-rise and single storey office buildings may sometimes be similar to houses, particularly if timber frame construction is used. Houses (or house-like buildings) used as office buildings would probably differ mainly in their fittings and usage pattern.

Table 1 lists a range of parameters relevant to climate change where office buildings and houses may differ. The information has been derived from a range of sources, including surveys, research reports, and discussions with BRANZ staff and people in the industry. The quality of the information will vary, and is open to discussion. From this information, Table 3 has been derived as a list of climate change impacts that may be different for office buildings. Each of these impacts is analysed in the remainder of this report.

3.3 How Do Office Buildings Differ from Houses?

Factor	Office buildings	Houses	Climate factor
Construction type	Construction varies, concrete/steel common	Mainly timber frame,weatherboard cladding	GHG, UV, flooding
Building form	≥3 storeys 20% by area[1]	Detached common	Flooding, GHG, overheating
Area[1]	By number, 43.2% < 300 m², By area, 8.3% < 300m²	By number, 92.3% < 300m² BY area, 90.0% < 300m²	Adaptation, GHG
Main materials[2]	Concrete/steel frame common on large buildings. Wall ≈40% concrete Roof ≈80% steel	Timber frame. Wall: Weatherboard, masonry, fibre-cement, stucco Roof: Steel, tile (most common material first)	GHG, flooding
Site levelling	Sites levelled	Less site levelling	Flooding
Roof type	Some low-pitch roofs	Low-pitch roofs uncommon	Wind
Foundations	Mainly on ground basements	Many above ground[3]	Flooding
Design	Often specifically designed	Rarely specifically designed	Wind
Demographics[1]	11% area, 3% count	58% area, 87% count	
Storeys[1]	By number, 97.0% < 3 storey By area, 79.2% < 3 storey	By number 99.9% < 3 storey By area, 99.3% < 3 storey	Wind, flooding
Services	Heavily serviced (HVAC, lifts, etc), some in basement.	Few services	Flooding, GHG
Zoning	Zoned office/commercial	Zoned residential	Flooding
Occupied hours	Occupied during work hours	Occupied mainly in evening and weekends	Heating, GHG, overheating
Refitting[4]	Extensive refit <10 years	Unknown, on property sale ~15 years?	Overheating, GHG
Tenure	Mainly rented?	70.5% owner-occupier[5]	Adaptation
Tenant duration	Variable, 10 yr lease common?	5-7 years?	Adaptation
Owner/Wealth	Investors/wealthy owner	Full range of income owners	Adaptation
Air-conditioning	Sometimes air-conditioned (12%)[6]	Rarely air-conditioned[7]	Overheating, GHG
Heating	Heated	Marginally heated	GHG
Energy costs	Energy cost important	Energy cost important	GHG
Lighting	Light levels important	Light levels not important	GHG
Energy source[8]	60% electricity, 15% gas	72% electricity, 8% gas	GHG
Polymers	PVC, rubber, plastics, silicone, asphalt	Paint, PVC, in claddings, plastic, rubber	UV

Table 1. Exploring the differences between office buildings and houses.

[1] Isaacs (1998). Commercial category, not specifically offices. Includes, for example, restaurants, supermarkets, service stations.
[2] From Isaacs, Donn, Lee, et al (1996), Appendix C. The construction type of the building structure is not surveyed, only the claddings.
[3] The current trend is for houses to have concrete slab floors. Page reported that concrete floors were cheaper than timber floors by up to $20 per m² for domestic construction at 1998 prices.
[4] See Section 5.3.3, page 27
[5] Statistics
[6] See Section 5.7, page 35.
[7] Roussouw reported approx 2% of households had an air-conditioner.
[8] Figures from Ministry, Table B.3 year ended March 1997. Commercial and Residential categories only.

Grouping the information according to the climate change factor gives:

Flooding	construction type, building form, materials, site levelling, foundations, no. storeys, service, zoning.
GHG emissions	construction type, building form, area, materials, services, occupied hours, refitting, air-conditioning, heating, energy costs, lighting, energy source.
UV effects	construction type, polymers.
Adaptation	building form, tenure, tenant duration, owner/wealth.
Wind	roof type, storeys.
Overheating	building form, occupied hours, air-conditioning.

Table 2. Climate change factors and relevant differences between office buildings and houses.

Climate Impact	Different for Offices	Analysed
Decreased Winter Space Heating	Y	Y
Decreased Water Heating Energy	Slight	Some
Increased Overheating and Air-Conditioning Load	Y	Y
Degradation of Polymers	Y	Some
Increased Inland Flooding	Slight	Some
Changes in Wind	N	N
Increased Tropical Cyclones	N	N
Increased Coastal Flooding, Erosion, and Rising Water Tables	Slight	Some
Increased Insurance Costs	?	?
Increased Costs due to Carbon Charges	Y	Y
Changes in Electricity Costs	N	N
Changes in Timber Properties	N	N
GHG Emissions of office buildings	Y	Y

Table 3. Summary of climate change issues researched further for office buildings.

4. CLIMATE CHANGE IMPACTS ON OFFICES

4.1 Increased Tropical Cyclones

This is a highly uncertain risk, as indicated in Camilleri (2000a). To the extent that office buildings differ in response to coastal and inland flooding impacts, rainfall, and wind impacts they will respond differently (see individual sections). As for houses, office buildings are not designed to withstand tropical cyclone wind speeds, and would be expected to fail. Failure could be major structural damage or total collapse, or possibly the partial or complete loss of cladding sufficient to reduce the total wind-load on the structure to a level that prevents damage or collapse.

4.2 Wind

If office buildings are designed to match specific loads, rather than a more generic and conservative standard for houses, the design loads may be less conservative than for houses. The assessment in Camilleri (2000a) that changes in wind return periods for ultimate structural failure would be practically impossible to detect applies to office buildings also. Changes in the frequency of failure of claddings and other similar building elements would be easier to detect, but still difficult, especially with the added factors of cladding age, expected service life, and installation details.

4.3 Decreased Water Heating

Office building water heaters will have the same decrease in water heating energy as houses, provided that the water supply is not heated or cooled before entering the heating system, and the system is not a heat pump (which would result in slightly greater reductions, as the efficiency is greater at higher temperatures). Standing losses should decrease for buildings that maintain higher temperatures with climate change. Decreases of 1-3% per 1°C temperature increase are possible as a result of higher water temperatures entering the system, and higher average internal office temperatures (especially night-time temperatures, which are often uncontrolled).

4.4 Increased Insurance Costs

As for houses, if office building damage increases due to increased flooding or tropical cyclones, premiums are likely to rise. A change in the perceived risk of damage could also increase insurance premiums. Increased flooding is a likely cause of increased building damage. Increased damage from tropical cyclones is also possible, and the increase in damage could be very marked. Insurance costs for liability associated with Indoor Air Quality (IAQ) problems such as occupational health effects, disease, absenteeism etc could increase with warmer temperatures.

4.5 Increased Costs due to Carbon Charges

Carbon charges would increase fuel and energy costs directly, and also the cost of building materials, especially for aluminium, steel, concrete, and glass.

As noted in Camilleri (2000a), the increased energy costs due to carbon charges are likely to be small, at most a few percent, and it is hard to imagine how such small rises in energy costs would stimulate energy efficiency.

Increased building costs are also likely to be only a few percent or less. This level of increase is well within the range of short- and long-term price changes. See Camilleri (2000a) for more detailed information and calculations. The lowest GHG emission material is often not the cheapest, and this is unlikely to change even with carbon charges. For high-rise buildings in particular, the material choice is dictated by cost and structural demands, and widespread substitution of steel and concrete with timber may be problematic, costly, or technically impossible. There is the possibility of further optimisation of the amount of material used, but it is likely that designs are already highly optimised. Recent trends in multi-storey wooden construction are interesting, and could reduce carbon costs for initial construction compared to concrete and steel construction.

4.6 Changes in Timber Properties

As for houses, a potential problem exists if shorter growth cycles lead to timber that is more susceptible to distortion, or weaker.

4.7 Polymer Degradation

Rates of polymer degradation may change with climate change, though it is difficult to quantify, and rates for various materials could decrease, increase, or remain the same.

If the construction of office buildings makes greater use of polymers (e.g. for sealing windows and glass) than houses, they may be more vulnerable to any changes in polymer degradation. In office buildings, glazing systems using polymer sealants, rubber, or plastic seals and fasteners, or polymer glazing coatings, and roofing systems using rubber, plastic, and silicone may be affected. Glass facades rely on sealing systems using rubber, plastic, and silicone (or similar) sealants. All of these sealing systems degrade in time with UV and temperature. Flat or low pitch roofs sometimes use membrane type roofing materials (asphalt, rubber, butyl, PVC) all of which are subject to deterioration.

Quantifying the reduction is not yet possible, though in the worst case scenario for temperature increase alone (reaction rate increase of 20% by 2070, with no reduction in UV levels), the service life would be reduced by about 20%, giving a reduction in service life of five years over a 25 year service life.

The service life of many polymer-based building materials ranges from 5 to 25 years, so there are many replacement cycles in the 70-year time-scale of the climate change studied here. Therefore changes in service life in the 30-70 year time-scale considered for climate change are not immediately relevant, as there is time to change building products before the impacts of climate change are felt. The actual service life of many modern building materials is not actually known, but is estimated by durability studies. Any failure of a material to fulfil its expected service life should be detectable by the manufacturers, and programmed maintenance or other steps taken to ensure acceptable life under the future climate.

4.8 Changes in Electricity and Energy Costs

Office buildings will face increased electricity and energy costs because of carbon charges of perhaps a few percent. Figures from Section 5.6 put the net operational annual energy use per m^2 for lighting and HVAC in the range 382-634 $MJ/m^2/yr$.

4.9 Flooding

4.9.1 Inland Flooding Risk

Changes in the risk of inland flooding for office buildings will be identical to houses, at from no change to twice the AEP by 2030, and no change to four times the AEP by 2070. What may be different is the susceptibility of office buildings to flooding damage, as they may differ from houses in the following factors: location; construction type; building form; materials; site levelling; foundations; number of storeys; services, and zoning. How these factors may affect the risk of damage from flooding is discussed in this section.

Office buildings are likely to be at greater risk of flooding than houses (especially in some CBDs), and would be expected to suffer more than houses from climate change induced flooding (see Section 4.9.2). With the possible higher incidence of flooding, changes in flooding incidence for office buildings may be easier to detect than for residential property, but will still be difficult.

The risk of increased urban flooding from stormwater is likely to rise, and perhaps much more than river flooding, but this is extremely difficult to quantify (see Section 4.9.5).

4.9.2 NZBC, Building Act, and Zoning

In Clause E1 of the NZBC (BIA 1995) it is stated in Clause E1.3.2, Limits on application: 'Performance E1.3.2 shall apply only to Housing, Communal Residential and Communal Non-residential buildings'. Therefore, there are no NZBC restrictions on the acceptable flooding risk for commercial buildings, unlike houses where there is a limit on the acceptable AEP of over the floor flooding of 2%.

Section 36 (1) of the Building Act 1991 requires territorial authorities to refuse to grant a building consent if the land or building is likely to be subject to inundation (i.e. flooding), and other risks including erosion, slip, and subsidence. Under Section 36 (2) a building consent may be granted provided that an entry on the certificate of title is made that the land is subject to the risks described in Section 36 (1). Further, if a consent is granted under Section 36 (2), Section 36 (4) states that the territorial authority shall not be under any civil liability on the grounds that the consent was issued in the knowledge that the land or building was at risk. The risk and consequences of flooding therefore lie with the owner, and subsequent owners of the land and building(s), provided that the entry on the certificate of title is made properly. Note that Section 36 only covers erosion 'where a river gradually and imperceptibly washes away one of its banks' (Hinde and Hinde, 1995), so sudden erosion by a single flooding or storm event does not come under Section 36, but is covered by the Resource Management Act 1991.

These provisions of the NZBC and Building Act mean that there is not a national, preset level of acceptable flooding risk for office buildings as there is for houses, and that there is the potential for building consents on flood-prone land to be issued at the discretion of territorial authorities. A likely result of this is that some office buildings may be built with flooding risks higher than the 2% AEP limit for houses.

Zoning can be a powerful tool for flood-management. For example, flood-prone areas (river banks and adjacent areas) may be zoned for recreational use only. Areas with lower risks can be zoned for commercial buildings, and areas with even lower risk areas for residences. This risk differentiation serves to maximise land utilisation while minimising the damage and disruption caused by flooding. Many floodplain management schemes around New Zealand use such zoning approaches. However, where cities and towns developed before floodplain management was put into place, this approach is not possible, and many commercial centres have been built in areas vulnerable to flooding (e.g. Wellington CBD; Lower Hutt; Petone; Opotiki; and Greymouth to name but a few). Once commercial centres are established, they are very costly to move as the property values are very high, and they are the essential heart of the town's infrastructure. The trend in the past in New Zealand has been to provide flood protection schemes for such areas (e.g. The Greymouth and Hutt River protection schemes), often at great expense.

The overall flooding risk of office buildings is therefore likely to be higher than for houses.

4.9.3 Costs of Flooding: Stage Damage Curves

Examples of stage-damage curves developed for the Wellington Regional Council (1992) are used to show the costs of flooding damage by flood height and building type (see Table 4 through Table 9). Office buildings have the highest overall flood damage cost per m² floor area of any building type for over-the-floor flooding. This is mainly due to the large amount of expensive electrical and electronic equipment in a typical office building, and internal linings readily damaged by water (e.g. wallpaper, carpet). Computers, fax and photocopy machines, telephone and network systems would likely be written off if inundated by flood waters. Indirect costs and days lost are also high as the repairs required are extensive, specialist equipment needs replacing, and it takes time to re-establish computer systems, paper work, and record systems. The actual cost in a given office building will vary, but the figures here give a useful reference point.

Changes in Annual Average Damage (AAD) for individual buildings are not expected to differ much from those for houses, as the stage-damage curves have 'f' similar shapes, though the total cost of damage is higher at each stage for office buildings (see Table 4 through Table 9). However, where large, fairly flat areas border so-called 'flood risk lines' (such as the '1 in 100 year' flood line), many buildings may be simultaneously exposed to a uniformly increased risk, which would give the whole area a net increase in AAD for the area greater than the change in flooding risk (for example Smith et al found increases in AAD of up to ten times where the AEP increased only four times).

Businesses that have insurance cover for flooding can expect to recoup some of the loss, but generally the indemnity value of chattels will be at less than replacement value. Indirect losses are less likely to be recoverable through insurance (Wellington Regional Council, 1992).

Table 4. Flood stage damage for timber floored residential buildings[9].

Depth (cm)	Total Cost ($/m²)
Just below floor	39
5	126
50	541
200	920

Table 5. Flood stage damage for industrial buildings.

Depth (cm)	Direct Cost ($/m²)	Indirect Cost ($/m²)	Total Cost ($/m²)	Days lost
0	3	0	3	0
15	44	8	52	7
50	332	65	397	16
100	648	82	730	26
200	864	121	985	49

[9] Note that buildings with concrete floors should suffer little or no damage with 'just below floor' flood depth, and less damage for 5 cm flood depth. Extracted from Wellington.

Table 6. Flood stage damage for retail buildings.

Depth (cm)	Direct Cost ($/m²)	Indirect Cost ($/m²)	Total Cost ($/m²)	Days lost
0	0	0	0	0
15	53	4	57	5
50	208	7	215	9
100	516	17	533	19
200	690	39	729	29

Table 7. Flood stage damage for commercial service buildings.

Depth (cm)	Direct Cost ($/m²)	Indirect Cost ($/m²)	Total Cost ($/m²)	Days lost
0	0	0	0	0
15	140	2	142	1
50	240	199	439	21
100	377	242	619	27
200	743	242	985	27

Table 8. Flood stage damage for wholesale buildings.

Depth (cm)	Direct Cost ($/m²)	Indirect Cost ($/m²)	Total Cost ($/m²)	Days lost
0	0	0	0	0
15	28	4	32	5
50	450	7	457	9
100	691	17	708	19
200	981	39	1,020	29

Table 9. Flood stage damage for office buildings.

Depth (cm)	Direct Cost ($/m²)	Indirect Cost ($/m²)	Total Cost ($/m²)	Days lost
0	0	0	0	0
15	17	104	121	1
50	46	1,088	1,134	33
100	1,839	1,191	3,030	34
200	1,918	1,761	3,679	47

4.9.4 Vulnerability to Damage

Once a building is flooded, many factors govern the extent and cost of the flooding damage. **Construction type** and **materials** affect both the vulnerability to flooding (floor levels) and the likely damage. For example, particle-board and plasterboard require maintenance, repair or replacement after flooding, whereas concrete floors and walls are often undamaged and can be cleaned quickly. Concrete floors flooded to just below wall level should be virtually undamaged (though water may be trapped under the slab), but timber floors are damaged as the bearers, flooring, and insulation are submerged (BRANZ Bulletin 240, 1984). In high flow, high flood level events, heavyweight construction (e.g. concrete foundations and walls) is generally more likely to withstand the water pressure than lightweight (e.g. timber foundations and walls) (Smith et al). Concrete **foundations** and floors are often closer to ground level than those made from timber, and so the building may be more likely to be flooded. **Site-levelling** before construction can lower floor levels further.

Multi-storey buildings will only flood on the ground floor (except in the very rare floods with depths of around 3 m or more), limiting the damage to the ground floor. However, **services** in office buildings (lifts, boilers, plant, switchboards, computer networks, telecommunications etc) are often on the ground floor or in the basement, vulnerable to flooding. So, flooding to only the ground floor or basement can paralyse a multi-storey building. The actual damage may be confined to the ground floor, but the indirect damage (loss of business etc) could affect all floors. The simple precaution of placing vital **equipment and services** above ground level, or flood-proofing key areas, could make the difference between minor disruption, and days or weeks of lost business (or even business failure).

4.9.5 Stormwater

Rivers are not the only source of flooding in urban areas. Stormwater drainage systems can become overburdened in heavy rain, or by blockage, causing localised flooding. Stormwater systems that drain to flood-prone rivers, estuaries, or the sea can suffer reduced flow, blockage, or surcharging (reverse flow) when the outfall floods. On many rivers, large valves block stormwater drains when flooding of the main drain or river occurs. Floodwater then builds up in the stormwater system.

On large commercial properties, storm water drainage must be included on the site. If the stormwater system has been designed to handle a maximum intensity/duration of rainfall (as is specified in Clause E1 of the NZBC (BIA 1995) which states that at Clause E1.3.1 is at the 10% AEP), then as rainfall AEPs increase with climate change, drainage systems would be over-capacity more frequently. With climate change, this could increase up to a 40% AEP. What happens when the system does not cope? The system will either flood behind the drain, causing problems on-site, or find another path, causing problems on-site and to adjacent sites. If there are many interconnected drainage sites, then the consequences of multiple drainage failures may be very serious, though difficult to predict without sophisticated hydrological modelling. As the AEPs increase with climate change, single and multiple failures of urban drainage systems will become more common, and the likelihood of multiple failures leading to serious flooding will increase. How much this will increase is impossible to assess without sophisticated modelling, but it is likely to be highly non-linear. If the flooding goes beyond the nuisance value of, for example, a flooded car park, to entering buildings or basements, then this could become a major problem.

As urban centres grow, the flooding risk from stormwater will change, affected by factors such as the area of impermeable surface, street and drain layout, population density etc. In many cities and towns there has been insufficient time under the present stormwater performance and climate to estimate the rainfall to flooding relationship. Therefore, extrapolation from current performance to future performance (as was done for the inland flooding assessment in Section 4.9.1) is not possible, as the baseline performance is poorly understood, and in areas with ongoing development the future performance is unknown.

Urban catchment areas are amongst the most difficult to model in hydrology, despite the fact that it is possible (with sufficient effort) to map the entire drainage network, and model the ground area and building drainage. The response times of catchments to drain are normally very short (seconds to minutes), and once in the drain, flow speeds are high. Drainage in the network of pipes can actually become mathematically chaotic, as pipes fill and block, flow backwards, and interact with other pipes through junctions. An example of the level of sophistication required to control urban drainage networks is the integrated radar, raingauge, and network control system based in Manchester (Cluckie, 1999). It uses high time and spatial resolution rainfall data, in combination with detailed, real-time modelling of the drainage network, to control the stormwater flow and reduce local flooding and excessive discharges to eco-systems. There does not appear to be anything on this scale for New Zealand. If such systems existed, then a detailed analysis of the effect of climate change on urban hydrology would be feasible.

Office buildings may therefore be exposed to an unknown, increased risk of stormwater flooding with climate change. Currently, there appears to be no suitable method for assessment. The lower limit of increase in AEP would be the same as for inland flooding, but there are many factors that could lead to larger increases.

4.9.6 Coastal Flooding

The changes in risk to office buildings from coastal flooding appear to be no different than for houses. Similar risk factors for potential damage apply as for inland flooding of office buildings. Basements may be a particular problem if they are low-lying and drain to the sea, or are below sea-level. If rising sea-levels newly expose buildings or land to wave-action, then huge damage can result as the loads are far higher than for wind or earthquake, and foundations can collapse from undermining (Jones, 1997).

4.10 Heating and Cooling Load, and Overheating

4.10.1 Introduction

This section gives the results of building energy simulations performed to study the likely change in building energy requirements with climate change. A full report on the simulation work appears in Energy Group (1999).

As office buildings are occupied during the day, and some people are often unable to change their location in a building, control of overheating is more important than for houses. Large commercial buildings are cooling-load dominated for many New Zealand cities, so increasing temperatures may increase energy use, whereas for houses, increasing temperatures should decrease energy use (Energy Group, 1999). Many office buildings are air-conditioned, and increases in temperatures would require increased air-conditioning use, and possibly increased plant capacity. For unconditioned buildings, small increases in temperature may dramatically increase the number of uncomfortable days. For specially designed, passively ventilated buildings, the design may fail to achieve the planned range of temperatures with climate change induced temperature increases.

4.10.2 Model Process

The DOE-2.1E building energy simulation program (Winklemann et al, 1993) was used to model two different buildings in both Auckland and Christchurch. One building was a 'generic' model building, and the other a building specifically designed to be naturally ventilated. Each building was run as both free-running and fully air-conditioned. The model was run using climate change scenarios for 2030 and 2070, and a reference year (1991) (Energy Group, 1999). The results were hour-by-hour energy use and temperatures for the model buildings.

4.10.3 Scenarios

Scenarios of increased temperatures with climate change were used as the basis for the weather data files required by the building energy model. The weather data files consist of one complete year of hourly data for a number of meteorological variables: dry bulb temperature, wet bulb temperature, dew point temperature, wind speed and direction, and solar radiation. These files were based on the 1991 climate year for Auckland and Christchurch, with the temperatures modified to account for climate change, and idealised changes to the humidity. No allowance has been made for changes in the comfort perceptions of people as temperatures increase.

4.10.4 Change in Heating and Cooling Load

The results of the heating and cooling-load simulations are presented in Table 10 to Table 13. In both Auckland and Christchurch there is a net ***increase*** in energy use for heating and cooling combined, with much larger increases for Auckland. When the percentage increase in energy use is plotted against the temperature increase (Figure 1), the differences in building behaviour between Auckland and Christchurch become obvious. In Auckland there is a sharp increase in energy use with increasing temperatures. In Christchurch there is almost no change (<1%) for increases of up to 0.9°C, and only at most a 6% increase for an increase of 2.7°C (the temperature at which energy use starts to increase significantly for Christchurch was not determined).

The reason for the difference in behaviour is the balance between the heating and cooling-load. In Christchurch, the annual heating is similar to the annual cooling energy (Table 10), and the decrease in heating is approximately equal to the increase in cooling energy for temperature increases of <0.9°C. Once the building becomes cooling-load dominated, any further increase in temperature gives a large increase in cooling-load. In Auckland, the office buildings are already cooling-load dominated, so any reductions in heating energy are much smaller than the increases in cooling energy, and the net energy increases sharply with increasing temperatures.

Note that a major difference between the 'Generic' and 'Real' building is the presence of louvre shading on West facing windows, overhang shading on the North, and planted trees for shade on the 'Real' building. These differences reduce cooling energy consumption, and are responsible for much of the 30% reduction in energy use for the 'Real' over the 'Generic' building.

	Auckland			Christchurch		
	1991	2030	2070	1991	2030	2070
Heating load	4.0	3.7 - 2.9	3.3 - 1.4	13.5	12.9-11.3	12.1- 7.8
Heating energy	4.0	3.7 - 2.9	3.3 - 1.4	13.5	12.9-11.3	12.1- 7.8
Cooling load	49.0	52.2-60.5	56.2-88.4	28.0	30.7-35.0	32.7-51.0
Cooling energy	14.8	15.8- 9.3	17.0-26.8	8.5	9.3 -10.6	9.9 -15.5
Total energy	18.9	19.5-21.3	20.3-28.2	22.0	22.2-21.9	22.0-23.3

Table 10: The predicted heating and cooling energy for the generic building in kWh/m²/yr (coefficient of performance (COP) is 1 for the heating and 3.3 for cooling)

	Auckland			Christchurch		
	1991	2030	2070	1991	2030	2070
Heating load	1.2	1.0 - 0.7	0.8 - 0.2	8.4	7.7 -6.3	7.0 - 3.3
Heating energy	1.2	1.0 - 0.7	0.8 - 0.2	8.4	7.7 -6.3	7.0 - 3.3
Cooling load	31.2	33.6-39.4	36.3-59.3	14.0	15.6-18.9	17.2-31.0
Cooling energy	9.5	10.2-11.9	11.0-18.0	4.2	4.7 -5.7	5.2 - 9.4
Total energy	10.7	11.2-12.6	11.8-18.1	12.6	12.5-12.0	12.2-12.7

Table 11: The predicted heating and cooling energy for the real building in kWh/m²/yr (COP is 1 for the heating and 3.3 for cooling)

	1991	2030 Low	2030 High	2070 Low	2070 High
Net energy	18.9	19.5	20.3	21.3	28.2
Net change		0.65	1.45	2.41	9.32
% Increase		3%	8%	13%	49%

Table 12. Change in net energy use for Auckland model generic building.

	1991	2030 Low	2030 High	2070 Low	2070 High
Net energy	22.0	22.2	22.0	21.9	23.3
Net change		0.17	0.00	-0.08	1.26
% Increase		1%	0%	0%	6%

Table 13. Change in net energy use for Christchurch model generic building.

	1991	2030 Low	2030 High	2070 Low	2070 High
Net energy	10.7	11.2	11.8	12.6	18.1
Net change		0.51	1.15	1.92	7.42
% Increase		5%	11%	18%	70%

Table 14. Change in net energy use for Auckland model real building.

	1991	2030 Low	2030 High	2070 Low	2070 High
Net energy	12.6	12.5	12.2	12.0	12.7
Net change		-0.16	-0.41	-0.64	0.01
% Increase		-1%	-3%	-5%	0%

Table 15. Change in net energy use for Christchurch model real building.

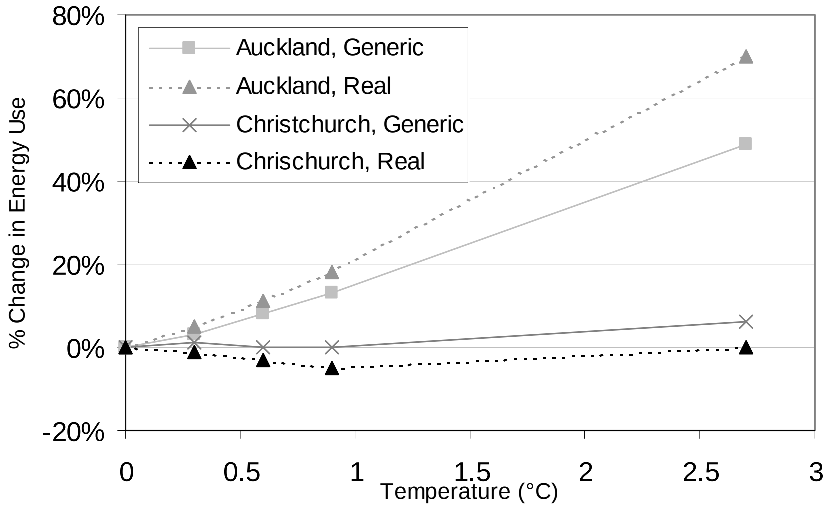

Figure 1. Change in energy use for simulated buildings.

4.10.5 Change in Number/Percentage of Uncomfortable Hours

The percentage of occupied hours of uncomfortable indoor temperatures (defined as 25°C or above during office hours) was also modeled for the buildings in Auckland and Christchurch (see Figure 2 and Figure 5). The percentage of uncomfortable temperatures increases with increasing external temperatures. This would be expected to influence the occupants' satisfaction with the buildings climate control, and could lead to the adoption of other climate control measures, including air-conditioning.

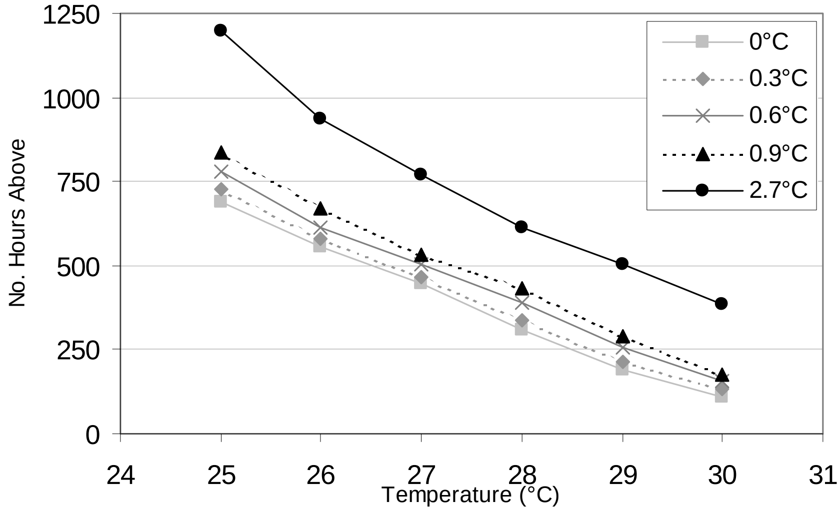

Figure 2. Number of hours above temperatures with rising temperatures, naturally ventilated buildings, Auckland.

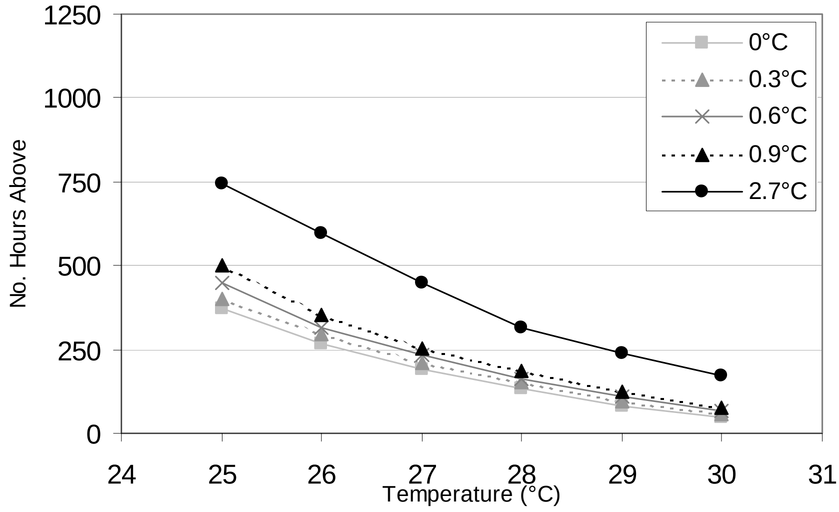

Figure 3. Number of hours above set temperatures with rising temperatures, naturally ventilated buildings, Christchurch.

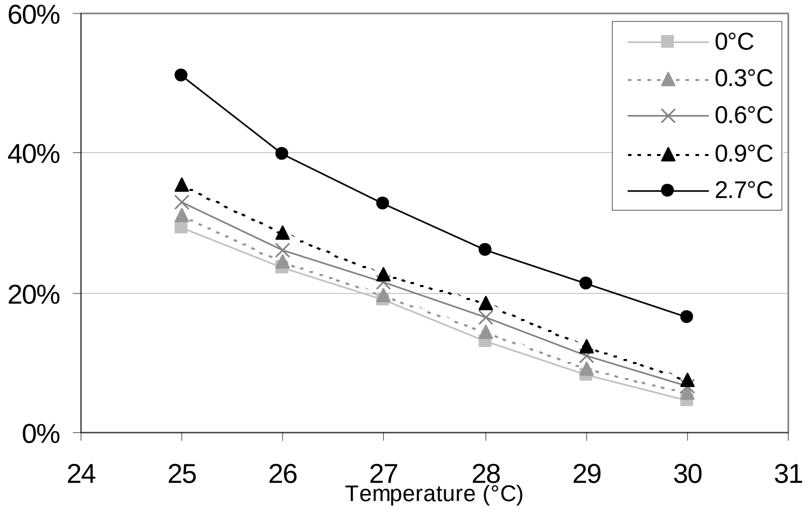

Figure 4. Percentage hours above set temperatures, naturally ventilated buildings, Auckland.

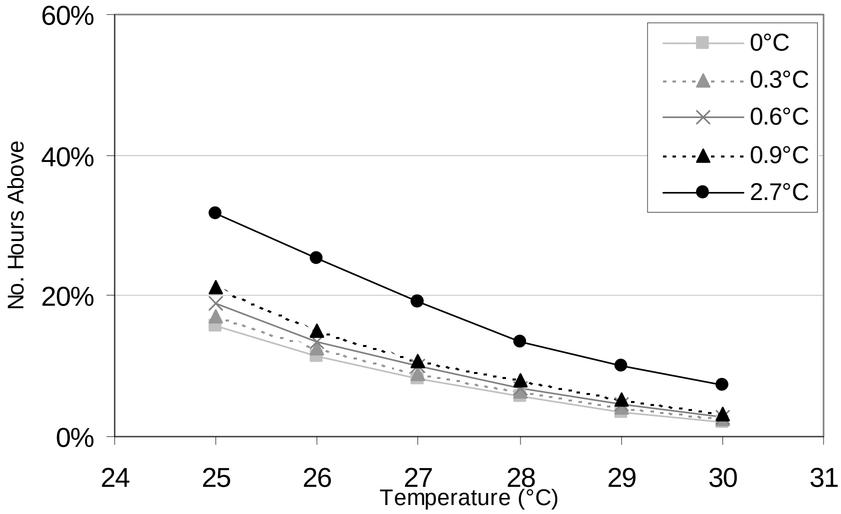

Figure 5. Percentage hours above set temperatures, naturally ventilated building, Christchurch.

4.10.6 Air-conditioned Buildings

Air-conditioned buildings can also overheat in very hot temperatures, if the system has inadequate peak capacity. For the modeled air-conditioned buildings under current climate (1991), temperatures above 25°C are rare, at «1% of occupied hours for both Auckland and Christchurch. Under the largest temperature increase of 2.7°C (2070 High), this rises to approximately 3% for Auckland, and 2% for Christchurch, and the temperatures do not exceed 27°C. Therefore the comfort conditions of the air-conditioned buildings are hardly affected by a 2.7°C temperature increase, in contrast to the same buildings with no air-conditioning where uncomfortable conditions would occur more than 30% of the time.

It is expected that buildings with sufficient air-conditioning capacity will be able to maintain comfortable temperatures, though at the cost of increased overall energy consumption in some regions (e.g. Auckland). If the air-conditioning system is undersized, then the building would be expected to overheat more with increasing temperatures.

4.10.7 Summary

Increased temperatures are likely to increase net heating and cooling energy consumption for many New Zealand office buildings. For the modelled air-conditioned buildings the change in energy use depended on the location. For the cooling-load dominated buildings (Auckland) energy use always increased with rising temperatures, by up to 50-70% by 2070. For the heating-load dominated buildings (Christchurch), increasing temperatures had little effect on energy consumption, as savings in heating energy approximately balanced increases in cooling energy. It is expected that similar results will hold for buildings in other locations.

Air-conditioned buildings with sufficient cooling capacity should have little change in comfort levels, but forced and naturally ventilated buildings may become progressively less comfortable, unless measures are taken to reduce overheating (e.g. shade, ventilation, load control, air-conditioning), or such measures are already included in the design.

If the results of these simulations are assumed to apply to other buildings in other New Zealand locations, then the following trends in energy and comfort conditions are anticipated:

- Decreased energy use for non-air-conditioned buildings in all locations
- Increased energy used for air-conditioned buildings in cooling-load dominated locations
- Greatly increased incidence of uncomfortable conditions in non-air-conditioned buildings, unless already specifically designed
- Little change in incidence of uncomfortable conditions in air-conditioned buildings, provided cooling capacity is sufficient
- Increased conversion of unconditioned to conditioned buildings

Most office building space is in the North Island, with a large amount in Auckland (Page, 1999), so most air-conditioned New Zealand office buildings would be expected to have increased energy use with increasing temperatures. It is difficult to estimate how the nationwide energy use would change, but assuming that 12% of offices are air-conditioned, and that all buildings behave as the Auckland Generic building, then nationwide total energy use in office buildings could decrease by up to 20% by 2070. The seasonal energy demand pattern would also change, with lower demand in winter, and higher demand in summer. If more buildings are air-conditioned in response to increasingly uncomfortable conditions then these potential energy savings may not be realised. More research and exploration into the behaviour of buildings and their occupants is needed in order to develop other responses to overheating which could avoid widespread increases in air-conditioning and their associated energy demands.

5. EFFECTS OF OFFICE BUILDINGS ON CLIMATE CHANGE: GHG EMISSIONS

The most direct effect of office buildings on climate change is from their GHG emissions. GHGs are emitted at all stages of a buildings life: from manufacture, occupancy, refurbishment, and demolition. GHG emissions are from fuel consumed for energy and transport, resource processing (e.g. steel, cement, aluminium manufacture), and directly from leaking or discarded HVAC systems.

In this section an approximate estimate of the life cycle GHG emissions of generic office buildings is made. The life-cycle stages considered are:

- Initial (manufacture and construction)
- Recurring (maintenance, refitting, and refurbishment)
- Operation (energy use)
- HVAC leakage
- Transport (commuting)
- Demolition

Transport emissions for workers commuting to office buildings have been included, as these emissions are comparable (or even larger) than the occupancy energy emissions for many buildings.

The life-cycle GHG emissions are summarised next, followed by the detailed analysis of each life-cycle stage in subsequent sections.

5.1 Summary of Office Building CO_2 Emissions

The life-cycle GHG emission figures reported here for office buildings are crude estimates only, drawn from a variety of sources of varying quality and applicability, and with many assumptions. It is unknown how accurate these figures are, but errors of 50% or more for each figure are possible. They provide a broad-brush picture of the emissions of office buildings in New Zealand. Much more research is needed to derive accurate figures.

The national figures are based on all office buildings. The Unit Area figures are based on either gross floor area or net letable area, as appropriate. The assumed building life is 50 years for all calculations, which is the minimum durability from the New Zealand Building Code.

The transport, initial and recurring combined, and operating emissions are each roughly 30% of the total, with most of the remaining 10% for HVAC leakage of refrigerants (See Figure 6). Figure 7 shows that the emissions for air-conditioned buildings are about 75% greater than those for non air-conditioned buildings (calculated assuming that all the HVAC leakage is attributable to the 12% of buildings that are air-conditioned, and adjusting the operating energies).

SOURCE OF EMISSIONS	NATIONAL ESTIMATED amount of CO_2 (kt CO_2 / yr) – gross	UNIT AREA ESTIMATED amount of CO_2 (kg/m^2 per year)	PERCENTAGE
Transport	218	24	33
Initial	67	9	10
Recurring	134	15	20
Operating	197	22	29
HVAC leakage	52	6	8
Demolition	Negligible	Negligible	Negligible
Total:	668	76	

Table 16. Estimated Office Building GHG emissions by life-cycle stage.

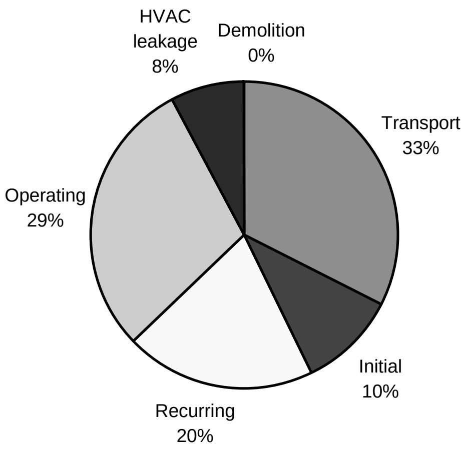

Figure 6. Proportions of GHG emissions by life-cycle stage.

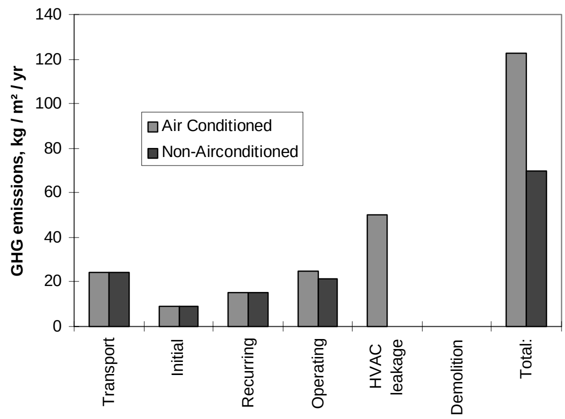

Figure 7. Comparison of GHG emissions for air-conditioned offices and unconditioned offices.

5.2 Energy GHG Emission Factors

A major issue in estimating life-cycle CO_2 emissions is how to assign CO_2 emissions for energy, as different energy sources have different associated GHG emission factors. Electricity is especially difficult, as it is supplied through the national grid, so it is difficult to track CO_2 emissions to the source. Electricity emissions for New Zealand range from near zero (wind and hydro) to 0.1 kg CO_2/kWh for the national average, to about 0.65 kg CO_2/kWh for fossil fuel thermal power stations, so there can be a large range of CO_2 emissions depending on the electricity source.

The emission factors used depended on the type of figures being estimated. For embodied CO_2 and refitting emissions, the figures of Honey and Buchanan (1992), which were calculated from estimates of actual process and energy emissions for structural components, and from average electricity for non-structural components were used. Energy-related GHG emissions for operational energy used the average GHG emission factors for the commercial building sector (derived from Ministry of Commerce (1997) [see Annex A - Emission Factors]. For transport, emission factors from Ministry of Transport (1995) were used, which have a 30/70 mix of syn-fuel to petrol.

5.3 Trends In Office Buildings

5.3.1 Summary

Based on Auckland and international market statistics, it appears that:

- there is a decreasing period between refits, now carried out at least every ten years
- large open office spaces are expected to be more intensively occupied, and
- increased numbers of offices are being fitted with an intelligent and flexible structure.

The authors were unable to source much NZ-specific information about expected lifetime and energy technology trends related to office buildings.

5.3.2 Introduction

The trends of three areas relating to office buildings are examined, and a brief overview given of what is known for New Zealand. The areas examined are:

- Refit/Refurbishment
- Building Lifetimes
- Energy Technologies.

5.3.3 Refit/Refurbishment

Most of the information on refits/refurbishments is based around Auckland market studies, and is assumed to be applicable for all urban areas in New Zealand.

Refit periods (time between refits) are determined by rental considerations, to keep up a competitive edge in a responsive market. Usually, refits are carried out at the end of a lease, at least every 10 years (Page, 1999). A report by Baileys Research (1999) on central city offices, stated that owners are forced into '*...large scale capital expenditure programmes to upgrade services, refit interior spaces, and some cases a full exterior refurbishment. The alternative will be to suffer the losses of inferior vacant office space, through reduced rental rates. Office fit outs are now designed for more intensive occupation with large scale open spaces, especially around the perimeter*'. They also indicated that generally only the newer or substantially refurbished high quality premises are capable of providing the operational and occupational productivity required. International research suggests major refurbishment is being undertaken at increasingly smaller intervals (Cole et al, 1996).

New office buildings are increasingly being constructed with an intelligent and flexible infrastructure that improves performance and reduces operating expenses, and is also 'future proofed' (Baileys Research, 1999). Future-proofing includes things such as:

- automation systems to support the environmental control at a personal level
- space management systems
- communication systems to process information.

As a result of this new infrastructure, the cost of energy, maintenance, security and refit are all expected to be lower on an operating basis than non-intelligent systems. Whether this equates to a lower or higher embodied energy intensity is unknown.

Clients are demanding more flexibility in their office space (focussed on tenant preferences) resulting in an increased need for refurbishment activity. However, the space requirements per office worker have decreased - from about 34 m^2/person in 1988, to about 18 m^2/person in 1998 (Baileys Research, 1999).

5.3.4 Building Lifetimes

There is very little information on the average or expected lifetime of offices, or even commercial buildings in general in New Zealand (Page, 1999). No New Zealand-specific studies appear to have been carried out in this area. It was estimated, however, that it would be much greater than 50 years (Page, 1999), and dictated by economic life rather than physical age. Actual trends in office building lifetime (i.e. whether it has changed over the last decade or not) are unknown. A default lifetime of 50 years, as is required by the NZBC, has been used.

5.3.5 Energy Technology

Commercial buildings have considerable potential to save energy costs (Herns et al, 1993). It is unknown whether, or how many, of these energy-saving options are being installed in new and existing buildings.

Examples of these energy saving possibilities include (Herns et al, 1993):

lighting: installation of specular reflectors; low loss iron ballasts, occupancy detectors, and automatic dimmers.

space conditioning: careful maintenance of systems; high efficiency electric motors in plant; passive solar design.

Since the early 1980s no NZ published data has been available to trace the effects on commercial sector energy use of new trends in commercial buildings. Some examples of the likely major changes are (Isaacs, 1993):

- improved air handling controls
- high efficiency light fittings and controls.

5.4 Initial Embodied Energy-Related CO_2 Emissions

5.4.1 Summary

The annual CO_2 emissions resulting from initial manufacture and construction of office buildings are estimated to be between 67 kt CO_2 (based on the amount of new construction) or 80 kt CO_2 (based on all the existing stock), assuming a life of 50 years. For concrete or steel construction, estimated emissions are about 9 kg /m^2/yr, and for timber 2.6 or 4.6 kg/m^2/yr, based on a 50 year building life expectancy.

5.4.2 Introduction

Initial embodied energy is the energy used to manufacture and construct a building, including energy used for resource extraction, transportation, and processing. Initial embodied CO_2 is defined analogously.

Cole et al (1996) summarised many international building-related embodied energy studies, with overviews of US, UK, Japanese, Australian and Canadian studies. The paper cites typical initial embodied energy figures, which range from 4 to 12 GJ/m^2 for office buildings. A case study building is also examined; a three-storey, generic (4,620 m^2) office building using wood, steel and concrete structural systems. The components of the case study building were separated into site work, structure, envelope, finishes, services and construction. For the case study building, initial embodied energy ranged from 4.26 to 5.13 GJ/m^2. It was found that the structure represents a significant but not dominant proportion of the total embodied energy of the building, with the building envelope being the largest single component.

A NZ specific study (Honey and Buchanan, 1992), examines embodied energy figures and CO_2 for two office buildings (of 2 and 5 storeys). Comparative figures for wood, steel and concrete framed structures were given, applicable to typical 3-8 storey commercial buildings, based on averaging the results of the two office buildings. In the modelling, the non-structural embodied energy CO_2 estimations were made using a 75% hydro-electricity generation, rather than an 'at-the-margin' mix. The averaged initial embodied energy figures range from 3.74 GJ/m^2 and 6.64 GJ/m^2 for timber and steel buildings respectively. These figures are comparable to those of Cole et al (1996) for initial embodied energy, although they are at the lower end of the spectrum. Cole et al (1996) suggested that the reason for this is the limited range of non-structural elements in the NZ study.

The way timber is treated in many studies, is important, as only sometimes is the carbon stored in wood accounted for. Honey and Buchanan (1992) assumed that timber has a carbon storage of 250 kg per cubic metre of wood based on the assumption of an oven-dry density of 450 kg/m^3, of which 37% is carbon. Table 17 provides a summary of the breakdown of basic building material carbon emissions.

Material	Carbon released (kg/m^3)	Carbon stored (kg/m^3)	Net carbon emitted (kg/m^3)
Treated timber	22	250	- 228
Glulam	82	250	- 168
Structural Steel	8,132	15	8,117
Aluminium	6,325	0	6,325

Table 17: Summary of carbon emissions for various building materials (after Honey and Buchanan, 1992)

Since there is a significant difference in carbon release when storage is factored into the equation, embodied energy values with and without carbon storage have been calculated to determine upper and lower boundaries. So what are the lower and upper bounds for the amount of office-related CO_2 emissions in New Zealand? For a lower bound, Honey and Buchanan (1992) figures were applied, where the assumption is made that carbon in wood is locked into timber permanently and is equal to 250 kg/m^3 of wood. For an upper bound, it has been assumed that there is no storage of carbon in wood. Refer to Table 18, which gives the averaged upper and lower bounds of two buildings – 2 storeys and 5 storeys.

Type	Initial embodied energy (GJ/m^2)	Lower Bound (carbon stored) ($kg\ CO_2/m^2$)	Upper Bound (no carbon stored) ($kg\ CO_2/m^2$)
Steel	6.6	462	480
Concrete	5.6	422	439
Timber	3.7	132	232

Table 18: Variation of initial embodied energy and CO_2 emissions for major structural elements (adapted from Honey and Buchanan (1992)).

On a per square metre basis, taking concrete and steel as being the primary structural materials, the initial-related CO_2 emissions range between 422 and 480 kg/m^2, with a simple average of 451 kg/m² .

The New Zealand total office area of 8.9 x 10^6 m² was derived from data from Valuation New Zealand (1994). Multiplying this area by the average emission of 451 kg/m² gives an estimate of the total carbon released in the creation of the existing office building stock:

$$451 \times 8.9 \times 10^6 = 4{,}014 \text{ kT } CO_2$$

Assuming that the average lifespan of a building is 50 years, the annual average figure is 80 kT CO_2 per year for all of New Zealand.

To find out what the average initial embodied energy figures are for more recent building stock, values for the last ten years 1980-1989 were analysed. Using the Valuation NZ data, it was found that on average 150,000 m² per year of new office space was constructed. This equates to **67 kT CO_2 per year** (using the simple average of 451 kg CO_2 /m² established previously).

Using the Table 18 results, and applying the average lifespan of the building (50 years) to the figures, the upper and lower bounds become:

Lower Boundary (based on a concrete building with stored carbon):

422 kg CO_2 per m^2 /50 years **= 8.4 kg /m^2 annually**

Upper Boundary (based on a steel building with no carbon storage):

480 kg CO_2 per m^2 /50 years **= 9.6 kg/m^2 annually.**

Taking a simple average of the two values above, gives an emission figure of **9.0 kg CO_2/m^2/yr.**

5.5 Recurring CO_2 Emissions

5.5.1 Summary

Recurring CO_2 emissions are those for repairs, maintenance, and refurbishment. The amount of CO_2 emissions resulting from the embodied energy due to the recurring activities in office buildings is estimated to be 134 kT CO_2/yr (i.e. 15 kg CO_2/m^2).

5.5.2 Introduction

Recurring embodied energy is defined as the energy required for building up-keep and refurbishment – i.e. the energy required for all non-structural work. Recurring embodied energy doesn't include HVAC energy or space heating energy.

A study by Cole et al (1996) identified two types of recurring embodied energy: *maintenance*, which includes such things as painting, carpeting, and other maintenance types of activity; and *refurbishment*, which includes significant materials replacement resulting from such things as office restructure and tenancy change. Cole et al believed that major refurbishments were being undertaken more often than maintenance. Typically, materials replaced have higher embodied energy intensities than structural/envelope elements, as they use materials such as plastics and copper that have significantly higher embodied energy intensities than basic structural materials.

For this study, the two types of recurring embodied energy have been amalgamated. The recurring embodied energy of an office building over fifty years was calculated. Because no studies on recurring embodied energy could be found for NZ, figures are based on overseas studies.

5.5.3 Process

Cole et al (1996) examined likely energy intensities for frequent and infrequent replacement, for three grades of office space – 'basic', 'medium' and 'top-grade'. The results are shown in Table 1.

OFFICE REFURBISHMENT/REPLACEMENT GRADE				
Units	**Basic**	**Medium**	**Top-grade**	**Replacement Period**
$GJ/m^2/yr$	0.20	0.28	0.41	FREQUENT
$GJ/m^2/yr$	0.12	0.18	0.20	INFREQUENT

Table 19: Recurring energy values for various replacements (after Cole et al, 1996)

Some assumptions were made in the calculation of these figures, including:

1) That a linear relationship exists between recurring energy and building age, as the figures were proportioned from 60 years to 50 years
2) that all future replacement materials are identical to those being replaced, with no allowances being made for improvements in manufacturing technology (this assumption will probably lead to an overestimation in costs); and
3) that the most likely office grade for New Zealand buildings is a 'medium' grade which has a mid-point replacement equal to 0.23 $GJ/m^2/yr$.

The New Zealand study by Honey and Buchanan (1992) reported that the non-structural components (i.e. those which get replaced/refurbished over the lifetime of those building), have an average embodied energy of 883 GJ [App. 4 – case study 4.3(a)]. For the case study building examined, this equated to a recurring embodied energy value of 0.10 GJ/m^2. Based on the current fuel mix, the total carbon released as a result of non-structural components equals 305 tonnes, or 0.036 t carbon/m^2 (i.e. 0.13 t CO_2/m^2). The relationship between recurring energy and CO_2 emissions for non-structural components then becomes 16,775 GJ equivalent to 1,116 t CO_2, for this case study building. Converting GJ to t CO_2, uses a multiplier of 0.067 (Honey and Buchanan, 1992). Applying this multiplier to the known average replacement energy intensity (i.e. 0.23 GJ/m^2/yr) results in 0.015 t CO_2/m^2/yr. Thus, the resulting emissions from recurring embodied energy for all office buildings nationally (which have an assumed area of 8.9×10^6 m^2), is **134 kT CO_2/yr**.

It should be noted that this doesn't account for the slight overestimation in not accounting for the additions due to new office buildings.

5.6 Operating-Related CO_2 Emissions

5.6.1 Summary

The operating-related CO_2 emissions (HVAC and lighting alone) is approximately 197 kT CO_2 /yr (22 kg/m^2) for all NZ office buildings.

5.6.2 Introduction

Operating energy varies greatly with building use patterns, climate, seasons, and efficiencies of the building systems. Operating energy is influenced by direct means - such as insulation standards and the efficiency of lighting fixtures, and indirect means - such as building management and climatic influences (Treleaven, 1993).

It is uncertain if there is a difference in the amount of operating energy for the differing (concrete, timber or steel) structural types of building. Cole et al (1996) found the differences to be negligible, while Treleaven (1993) found significant differences, with timber framed buildings being considerably more energy hungry.

Isaacs et al (1993) [based on BETARG] suggested a typical split of end-use energy is for New Zealand office buildings to be:

Heating	38%
Lighting	38%
Equipment	16%
Cooling	5%
Hot Water	2%

5.6.3 Studies

In the Canadian study by Cole et al (1996), the operating energy was estimated to be between 1.05 – 1.76 GJ/m^2/yr for a case study building with underground parking. Without underground carparking, the range became 0.959 - 1.64 GJ/m^2/yr. The figures were calculated based on current typical meteorological year (TMY) weather for Canada.

The NZ Energy Efficiency and Conservation Authority (EECA), Monitoring and Analysis Unit collected data on the energy performance of office buildings (1990-1995) (EECA, 1995), which gave an average figure of 168 kWh/m^2/yr or 0.61 GJ/m^2/yr. However, due to the great range of results provided and the lack of knowledge on what it included (eg car-parks, cafeterias, vacant floors, etc.), little confidence can be given to this average figure.

For the New Zealand specific study of embodied energy by Treleaven (1993), a medium-rise office building in Wellington was modelled, which used 207 MJ/m^2/yr on just HVAC alone. This was for a 25m square plan, four level building with no basement. If lighting is included, the energy use becomes 382 MJ/m^2.

In NZS:4220 (1982), the estimated total energy use for office buildings is 720 MJ/m^2/yr, based on a small survey of less than 2,000 buildings over a one-year period. Since no breakdown by end use is given, the HVAC and lighting proportions remain unknown. In another New Zealand study (Baird et al, 1989), a procedure was used to estimate the annual energy use by individual end uses of existing buildings. The energy use was normalised by floor area for a hypothetical building in Wellington with standard hours of occupancy. This study found that the average operating energy of skin and internal-load-dominated offices was 400 MJ/m^2/yr.

A summary of the various (net) operating energy intensities for HVAC and lighting is given in Table 20.

Source	Cole et al (1996) Canada	EECA (1995) New Zealand	Treleaven (1993) Wellington	NZS:4220 (1982) New Zealand	Baird et al (1989) New Zealand
HVAC and Lighting (MJ/m^2)	1,405[#]	532	382	634	400

Table 20: Net operational energy intensities for HVAC and lighting only

For this study, it was decided that the 400 $MJ/m^2/yr$ figure was as good an indicator as any (being roughly the average of all the NZ results), and was used for estimating office building CO_2 emissions.

From a Ministry of Commerce (1991) report on CO_2 emissions, commercial buildings (which are assumed to be representative of office buildings) have a CO_2 emission factor of 55.2 kT CO_2/PJ. This figure is averaged over all the fuel types for 1989[*]. Thus, if there is a total of 8.9 Mm^2 of office-type space in total, which uses an average of 400 $MJ/m^2/yr$ of operating energy, 3.56 PJ/yr is used. Converting this energy use to CO_2 emissions gives 196.5 kt CO_2/yr from operating energy alone.

5.7 HVAC-Related CO_2 Equivalent Emissions

5.7.1 Summary

The amount of CO_2 equivalent emissions resulting from the leakage of refrigerants used in office buildings is about 51.8 kT per year (i.e. 6 kg/m^2).

5.7.2 Background

About 99% of all currently installed air-conditioning systems in New Zealand office buildings use either a CFC or a HCFC as their refrigerant (Bowen, 1999). Both of these classes of refrigerants are detrimental to the ozone layer, and also have very large global warming potentials. If all the air-conditioning systems currently in operation never leaked and the coolants were effectively disposed of at the end of their useful lifetimes, this would not be a problem. Unfortunately, this is not the case.

At present, very little information is known on the current CFC to HCFC ratios used in commercial buildings, as very little data are available for the whole industry. For this study, calculations are based on a report by Royds Garden (1992), which estimated there were 180 CFC-11 air conditioned buildings nationwide, each containing an average charge of 275 kg, and that 90% of commercial air-conditioning systems in New Zealand are HCFC charged. Assuming this is the case, with only 10% of all buildings containing CFC-11 refrigerants, then in total, there are about 1800 commercial buildings nationwide which are air-conditioned. Assuming the charge in the CFC-11 buildings is the same as the amount in the HCFC buildings, then the total ‘banked’ refrigerant in commercial buildings is 495 t.

What proportion of commercial buildings are office-type buildings? Commercial buildings fall into five categories, according to Valuation New Zealand criteria - ‘accommodation’, ‘mixed use’, ‘office’, ‘retail’ and ‘other’ (Isaacs, Donn, Lee, et al, 1996). Only two categories are a concern for this study - ‘mixed use’ and ‘office’. Eighty percent of the ‘mixed use’ category is assumed to contain office space. As a proportion of ‘large’ commercial buildings (i.e. > 300

[#] Note the high figure reflects a more extreme climate.

*This is based on an energy use of 36.7 PJ of energy, which resulted in 2,027 kT CO_2 being produced in 1989. Since their definition for ‘commercial’ buildings includes hospitals, schools and hotels, the energy use figure should not be used for office buildings alone.

m^2) office and mixed use buildings account for 47% of all building area, based on nett area (see Table 21).

Uses	Gross Area (x 10^4 m^2)	Nett Area (x 10^4 m^2)
Accommodation	208	-
Mixed	540	432
Office	474	474
Retail	418	-
Rest	279	-
Total	**1919**	**906**

Table 21: Floor areas by building type (after Valuation NZ, 1994)

The amount of 'banked' refrigerant attributable to buildings coming under the 'office' category, is therefore estimated to be 0.47 x 495 Tonnes = 233 Tonnes. This estimation assumes that there is an even distribution of air-conditioning systems for all the 'commercial' building categories.

A substantial proportion of refrigerant used by the industry is to replace that lost from leaky systems (Bowen, 1993). Just what this leakage rate is unknown, but figures quoted by the EPA in the USA estimate that 60% of CFCs used in the refrigeration and air-conditioning industry are for after-installation replacement of lost refrigerant (Bowen, 1993). Leaks are known to be large scale, low frequency events, with a small leak often being intermittent in nature (Bowen, 1993).

For both major refrigerants, releases to the atmosphere are mainly brought about by leaks, with additional small amounts being released at the time of repair or as the equipment is removed from service. Collection of refrigerants from existing air-conditioning plants requires simple technology. The refrigerants are either reprocessed for further use or destroyed by incineration, depending on their purity (personal communication, Bowen) .

Losing refrigerant is an expensive business, with the new replacement (lower-ozone depleting) blends being considerably more expensive (Bowen, 1993). There is little research as to why systems leak and on better methods of protection. However, a limited survey has been conducted on the percentage of service calls requiring refrigerant replacement (Bowen, 1993). The survey found that simpler systems (less joints etc) have fewer leaks.

Since almost all the refrigerants used are either CFCs or HCFCs, the leakage calculations will be based on them.

The Global Warming Potentials (GWPs) of various refrigerants used in commercial building air-conditioning systems are listed in Table 22.

Refrigerant	GWP (cf CO_2 =1)
CFC - 11	3400[10]
HCFC - 22	1600[10]
HCFC - 123	90[10]
HFC 407 C	1624[10]
HFC 410 A	2025[11]
HFC 143 A	3800[11]

Table 22: Global Warming Potential (GWP) of refrigerants used in buildings

The estimated 233 t of 'banked' refrigerant used in 'office' buildings in New Zealand, requires replacement about once every 12 years (Bowen, 1993). The refrigerants are an estimated 90/10 split HCFC/CFC, with 60% of refrigerants being used for after-installation replacement of lost material. Thus, annually, 233/12 = 19.4 t of new refrigerant is needed. This 19.4 t equates to 40% of all refrigerants used. The remainder (60%) is for leakage replacement (29.1 t). Of this 29.1 t (90%) is for HCFCs with the remaining 2.9 t for CFCs.

Refrigerant Type	Amount (t) leaked	GWP#	Annual amount of CO_2 equivalent (Tonnes)
CFC-11	2.9	3400	9860
HCFC-22	26.2	1600	41920
TOTAL			**51 780**

Table 23: Amount of CO_2 equivalent from office buildings

Thus, the estimated total amount of CO_2 (equivalent) emissions from the leakage of refrigerants in office buildings in New Zealand annually: = **51.8 kT of CO_2/yr**.

So, what of the future? As part of international agreements, New Zealand has made a commitment to reduce emissions of ozone-depleting substances. In January 1996, New Zealand prohibited the consumption (i.e. manufacture plus import, less export) of new CFCs in bulk (i.e. container) form. It is still possible, however, to recover and reuse those CFCs already in New Zealand (Ministry for the Environment, 1998). HCFCs are also being phased out, so are being replaced. HCFC-22 replacements will be introduced in a two-staged process for all air-conditioning units. In the first stage, HFC 407C will be used. This is almost a direct replacement for HCFC-22, being relatively easy to fit. The second stage involves the use of HFC 410A, which is a much higher pressure system, requiring a total redesign of the system. However, it does improve its performance. Only in May 1999 did supply start for the HFC 407C replacement. It should be noted that both the major new replacements for HCFC-22 (i.e. R 407C and R 410A), have a higher global warming potential than the original refrigerant, and are also more likely to leak, as they have lower molecular weights (Bowen, 1993).

In the United States the EPA administers legislation aimed at curbing emissions of CFC and other refrigerants (EPA, 1999). The legislation requires building owners to keep records of their CFC stock in air-conditioning units, and follow strict protocols during maintenance to avoid leakage. CFCs are required to be phased out over time, and trading in recycled CFCs is severely

[10] After Butler
[11] After Takle (1997)
This is based on the international default standard of a 100-year timeframe.

regulated. Many individuals, companies, and even cities have been fined or imprisoned for breaches, with fines of hundreds of thousands of dollars, and lengthy prison terms (Environmental Support Solutions, 1999). In one case, the EPA is seeking $US27,000 **per day** from New York City for continuous violations since 1994. In contrast, New Zealand's approach is lower key, with a ban on the import of bulk CFCs and products containing CFCs, and restrictions on the discharge of CFCs while servicing or disposing of equipment (MFE, 1999). There are no restrictions on the use, sale, or recycling of the existing stockpile of CFCs.

5.8 Transport-Related CO_2 Emissions

5.8.1 Summary

The estimated annual amount of office CO_2 emissions from transportation of office workers is 24 kg per m^2. This is based on a net lettable area figure, adjusted for occupancy rate, and an estimated density of 21 m^2 of floor area per worker.

5.8.2 Introduction

In 1995, New Zealand's land transport contributed to 40% of the nation's CO_2 emissions (Ministry for the Environment, 1997). Just how much of these CO_2 emissions can be attributed to transport of office workers to and from the workplace is unknown, but is estimated here. To estimate the amount of transport-related CO_2 emissions, the following is required:

1) The amount of office floor space which is likely to be occupied on any given day.
2) The average distance to work for office workers.
3) The most likely mode(s) of transport used to get to work, and its corresponding CO_2 emission rate.

From these figures, an estimation of the overall CO_2 emission for all office workers can be derived. This three stage breakdown has been used to structure this section.

5.8.3 Process

The amount of office floor space which is likely to be occupied on any given day is dictated by:

- The office space available (i.e. the Net Lettable Area - NLA)
- The likely occupancy rate (i.e. the overall office vacancies), and
- The current occupied density

The NLA can be expressed as a proportion of the Gross Floor Area (GFA). For this study, the GFA was estimated using Valuation New Zealand's national survey data from April 1994. Valuation New Zealand categorises building types by use, of which only two types are relevant to this study: 'CO - commercial offices' and 'CX - mixed use buildings'. Mixed use buildings are mainly offices with one or two floors of retail use (Isaacs, Donn, Lee, et al, 1996). It has been assumed that 80% of mixed use buildings comprise office space, with the adjusted figures given in the table below.

Type	Total Floor Area (m^2)	Adjusted for Use (m^2)
Commercial Offices	5,214,570	5,214,570
Mixed Use Buildings	4,639,260	3,711,408
Total floor space available	**9,853,830**	**8,925,978**

Table 24: Floor areas for building types

For the purpose of this study the total adjusted floor space (or GFA) equates to 8.9 x 10^6 m^2 (refer Table 24). Although the data included in the Valuation New Zealand roll is of unknown accuracy, Isaacs, Donn, Lee, et al (1996) suggested that the floor area values are accurate to within ±10%. It should be noted that no accounting for building floor areas which were listed as missing or remodelled within the Valuation New Zealand data has been made.

The likely occupancy rate is reduced by two factors: the amount of floor space which can be actually utilised for work purposes (or Net Lettable Area), and the likely occupancy rate. It is estimated that Net Lettable Area (NLA) as a proportion of GFA ranges between 80-90% in an efficient building (Page, 1999). For this study, the average figure of 85% utilisation has been taken.

The NLA is further reduced by the actual area which is likely to be used at any one time (i.e. its occupancy rate), which is mostly dependent on market conditions. Only an Auckland-based figure could be gained for this estimation - so the assumption is made that Auckland is representative of all New Zealand. The overall office vacancy for Auckland over the last decade ranged from 9-30%, which prime office vacancy (in the heart of the CBD) ranged from 4-42%) (Baileys Research, 1999). At present, the vacancy rate is about 12%. A conservative estimate of 20% was taken for this study.

Factoring in NLA and occupancy, the estimated office floor area in NZ utilised on any given day becomes $0.85 \times 0.8 \times 8.9 \times 10^6$ = **$6.07 \times 10^6 m^2$.**

An estimate of the number of office workers using this space can be calculated when the typical density of workers is established. The density of office workers is known to be highly variable, ranging from 12-15m^2 per person for close working situations (such as typing pools), to greater than 27 m^2 per person for solicitors (Colliers Jardine Research, 1998). Previous construction-related studies have used a figure of 23 m^2 per person (Isaacs et al, 1996), but for this study, a more conservative figure of 21m^2 per person is used. The smaller value was used to reflect the downwards trend in fit out space per person. It can be calculated that $6.07 \times 10^6 m^2 / 21 m^2$ = **289 000** people work in offices on average, each day.

As urban density increases, transport fuel use decreases, and the densities vary greatly for New Zealand cities (Bachels, Newmann, and Kenworthy 1988). To find out just how far New Zealand office workers travel to work, national census 'Journey to Work' data was sampled, which gives average journey distances for the cities. Since the bulk of the offices will be in the larger urban nodes, the three most populated - Auckland (Waitakere, North Shore, Manukau), Wellington (Upper and Lower Hutt, Wellington and Porirua) and Christchurch, have been explored.

In 1991, the average 'journey to work' distances were:

	Auckland	Wellington	Christchurch
Travel Distance (kms)	12.6	10.6	8.0
Total Urban Population	956,500	346,200	316,000

Table 25: Journey to work distances for main urban centres. (After Bachels, Newmann, and Kenworthy (1998))

To get a better approximation of the average urban travel distance, the above figures can be weighted according to population. The population figures have been sourced for the respective Territorial Authorities from Statistics New Zealand (1998a), to give population-based weightings of: Auckland (0.60), Wellington (0.22), and Christchurch (0.18).

Multiplying the transportation distances by their respective weightings gives an average transportation distance for the three urban nodes of **11.3 km**. As this figure is representative of the bulk of all people travelling to work, it will be assumed to represent all people travelling to work in New Zealand.

The mode of transport is dependent on many variables – for example, in Hamilton, areas of low public transport use are generally close to the CBD, while areas of higher public transport use are concentrated around the areas of bus routes (Environment Waikato, 1988). (The probable reason for this – a 'flat fare' structure for bus trips). In a UK study by Daniels (1979), five towns were examined and it was found that car sharing increased as the distance to office establishments increases. The configuration of office development within each urban area also seems to exert some influence on the mode of transportation used.

The 1996 census (Statistics New Zealand, 1997) found that for all occupations, the transport modal distribution for people travelling to work was:

Private Car/Van	Company Car/Van	Passenger	Bus	Train	Motor bike	Push Bike	Walk	Other	Unknown
58%	13%	7%	3%	1%	2%	3%	8%	1%	3%

Table 26: Mode of travel to work

By far the majority (about 71%) drove a car/van to work, and the top four modes of transport were car/van, walk, pushbike – unknown - bus. Assuming that this split by mode is representative of office workers, the most likely form of transport is by car. From a study on transportation-related greenhouse gases (Ministry of Transport, 1995), it can be seen that the most likely fuel type used is petrol (96%).

Data for fuel consumption and passenger occupancy rates on a nationwide basis was not readily available for bus, train, motor bike and other forms of transport. To estimate the transport emission without this information, all vehicle transport was assumed to be by private car, and emissions for walking are assumed to be zero.

The mean engine size for New Zealand cars is 1872cc (rounded to 1.9 litres), while the CO_2 emissions for petrol is 2.7 kg CO_2/l assuming 100% combustion and a 30/70 blend of syn fuel/refinery mix (Ministry of Transport, 1995). The same study has shown that the fuel consumption rate can be expressed with the equation 1.43 x L + 3.58 for a car of this engine size, therefore the average petrol consumption is: 1.43 x 1.9 + 3.58 = 6.3 litre/100km (for city driving).

Thus, for an average commuting distance of 11.3 km, 0.7 litre of petrol is used each way. Thus, for the <u>return</u> journey, the amount of emitted CO_2 from travel to office = 2 x 0.7 x 2.7 = 3.8 kg of CO_2. But, accounting for ride sharing, the reduction factor = 0.91, so actual CO_2, emission per person is 3.5kg of CO_2.

The 3.5kg of CO_2 is an overestimation however, due to attributing <u>all</u> transport to petrol-driven cars, when walking makes up 8% of the main four modes of transport (and nominally gives off no CO_2). Accounting for walking, gives the multiplier of 0.92, and factoring it in results in an emission rate of 3.2 kg of CO_2 per person daily. Over a whole working year (236 days), this equates to: 3.2 x 236 = 755 kg CO_2 per person.

Over a whole year, each of the office workers are responsible for emitting on average 755 kg of CO_2. As there are an estimated 289 000 office workers, this equates to an emission of **218 kT CO_2 /yr,** from transportation. In terms of emissions per square metre of office space, this becomes:

$$\frac{218\times10^6 kg}{8.93\times10^6 m^2} = $$ **36 kg CO_2 per m^2 of office space, annually.**

5.9 Demolition-Related CO_2 Emissions

5.9.1 Summary

The demolition-related CO_2 emissions resulting from office buildings are considered to be too small to be of significance, when compared with the other office-related CO_2 emissions.

5.9.2 Introduction

There is a high degree of uncertainty surrounding demolition practices (Cole et al, 1996). As a consequence, predicting CO_2 emissions resulting from these practices is also highly uncertain. One of the main difficulties is estimating the likely energy associated with (and therefore the resulting CO_2 emissions) demolition practices fifty years in the future (Forintek, 1993). For any such future prediction, estimations on the likely technological advances, social climate and consumer needs have to be made - which is fraught with difficulty.

Most studies have found that the energy required to demolish a building at the end of its life is insignificant when compared to the other building-related energy requirements - such as initial embodied energy, operating embodied energy and maintenance-related embodied energy (Cole et al, 1996). From this, it can be assumed that the associated CO_2 emissions are also insignificant. Although there are few studies on the energy consumed in the demolition of a building, one study focused on a 5000 m^2 building, and split the energy values by the three main building materials types - wood, steel, and concrete (New Energy from Old Buildings, 1981). The study found the following demolition energy values: 27.1 MJ/m^2 wood, 87.7 MJ/m^2 steel, and 136.2 MJ/m^2 concrete. If the 55.2 kJ CO_2/PJ conversion figure is used (from the Ministry of Commerce, 1991), to give an indicative value, then it can be seen that an insignificant value results. Cole et al (1996) found that it was not useful or appropriate to differentiate between energy to dispose of the various building types because of its aggregated nature.

6. CONCLUSIONS

Climate change impacts on office buildings are similar to houses for most climate change factors. Climate change factors that were identified as affecting office buildings in a significantly different way to houses are:

1. Flooding
2. Extreme and temperature increases
3. GHG emissions
4. Carbon and GHG charges

Flooding effects on office buildings are broadly similar to those for houses, with increases in the incidence of flooding of from no change to four times by 2070. Increases in damage to office buildings may outstrip those of houses, because of differences in the stage-damage curves. As many office buildings are multi-storey, the risk of total loss is less than for houses, but with expensive electrical systems installed at ground floor level or lower, the potential for long-term disruption is high when flooding occurs.

The current flooding risk of office buildings is decided by the local territorial authority, the (original) building owner, or by historical accident. Some office buildings may have a risk of flooding greater than the minimum 2% AEP for houses mandated by the NZBC, and increases in flooding risk with climate change could make flooding a common occurrence for these buildings.

Office buildings in highly urbanised areas (especially those that have changed rapidly) may be at an unknown risk of future stormwater flooding, as the current flood performance of the stormwater systems is unknown, and the future performance difficult or practically impossible to predict.

The heating energy required for office buildings is expected to decrease if temperatures increase (based on simulations). The reductions vary with the location, and some locations may become almost heating free. For many buildings, decreases in heating energy could be equalled or exceeded by increases in cooling energy.

The cooling energy required for office buildings is expected to increase by approximately 5-20% by 2030 and 15-75% by 2070, depending on the building, location, and actual temperature increase. Existing air-conditioners should be able to handle this increased load, and cooling capacity can be increased if required when systems are replaced. Naturally ventilated office buildings may suffer increased overheating as temperatures increase, perhaps requiring overheating protection measures to be installed (e.g. shading, increased ventilation, night cooling, air-conditioning). For all building types, the number of hours of uncomfortable temperatures is expected to increase, with air-conditioned buildings the least affected, and unconditioned buildings suffering a large increase (unless they are well-designed passively cooled buildings).

Changes in the total energy required for heating and cooling for air-conditioned buildings have a more complex behaviour. For Auckland, any increase in the average temperature is likely to increase energy use, by roughly 15% per °C. For Christchurch, initial average temperature increases of <1°C give no change in total energy use, as reductions in heating balance increases in cooling energy use. Above 1°C energy use climbs similarly to that for Auckland.

It is difficult to quantify nationwide changes in energy use, but for the current building stock, a modest decrease in overall energy use is expected. However, as the building stock changes and cooling energy requirements increase, the potentially more widespread use of air-conditioning could lead to increased energy consumption and GHG emissions.

The effect of office buildings on climate change is mainly from GHG emissions, with most life-cycle emissions occurring for transport of workers and operation. The overall picture is that GHG emissions at all life-cycle stages are important (except perhaps demolition), whether from an initial or life-cycle point of view.

Carbon and GHG charges will likely increase the energy costs for office buildings. Energy usage and total cost is likely to rise for air-conditioned buildings, through increased energy use with increasing temperatures, and perhaps by charges for use or leakage of HVAC refrigerants.

7. CLIMATE CHANGE SUSTAINABILITY INDEX FOR OFFICE BUILDINGS.

7.1 Introduction

A framework for a Climate Change Sustainability Index (CCSI) was developed for houses in Camilleri (2000b). In this section, that framework is adapted for office buildings.

7.2 Issues for Inclusion in the CCSI

The issues included in the CCSI for houses were:

1. Inland Flooding
2. Coastal Flooding
3. Overheating
4. Tropical Cyclones
5. GHG emissions (space and water heating)

The CCSI is a numerical rating in two parts: one rating the impacts of climate change on the building, combining the first 4 of the above impacts, and another rating for the GHG emissions. No sensible methodology could be found for combining these two ratings into a single number.

To apply the CCSI framework to office buildings, the ratings for some of the issues needed to be changed. The changes are detailed in the remainder of this section.

7.3 Inland Flooding

Inland flooding risk for office buildings is no different to that for houses (see section 4.1, page 11), so the basic credit assignments based on known flooding risk or location are identical. Note that the height of the floor should be included in the height above river flood levels. The cost of flooding damage to office buildings is likely to be greater than for houses, and differences in building form (e.g. basements) can modify the extent of damage. These factors are taken into account in a simplified way in Table 27, with a maximum modifier of –2, as a building with all these features has only a slightly increased risk of flooding, though effects of flooding when it occurs are much greater.

Building Feature	Credit Modifier
Timber Floor	-1
Floor at or below ground level[12]	-1
Equipment in basement[13]	-1

Table 27. CCSI credit modifiers for office building flooding.

Note that there are no modifiers for multi-storey buildings, as even though the upper floors are only likely to be inundated by a flood of Biblical proportions, the operation of the entire building is likely to be affected by flooding to the lowest storey.

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

7.4 Coastal Flooding

Coastal flooding risk for office buildings is also similar to that for houses (see section 4.9.6, page 17), so use the same the basic credit assignments as for houses, with the modifiers as in Table 27.

7.5 Tropical Cyclones

No additional risk factors were identified for tropical cyclones (see Section 4.1, page 11), so use the same credit rating as for houses.

7.6 Overheating

The overheating rating attempts to rate how well the building will maintain comfortable temperatures with climate change. The overheating performance of office buildings is different from that of houses because of the size of office buildings, the construction materials, and the occupancy pattern.

Fully air conditioned buildings are likely to be able to maintain comfortable temperatures for most working hours with any likely increase in temperatures, albeit with increased energy consumption, so they get a large credit modifier. Special features to deal with overheating other than air-conditioning could include effective thermal mass, shading of windows, night cooling, and effective ventilation. Effective thermal mass can reduce peak temperatures during the day. Effective shading dramatically cuts the heat load from the sun, which can be a major contributor to overheating. Effective ventilation can replace warm inside air with cooler outside air, and aid cooling by sweating for occupants.

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. In terms of sustainability for climate change, the best option would be non-air-conditioning methods, which can give good temperature control with minimal GHG emissions if well designed and operated.

The detailed information on which this assessment is based is summarised in section 8 page 52. The procedure is to take the average maximum summer temperatures in Table 28, apply modifiers from Table 29 through Table 31, and then look up the CCSI credits in Table 33. For air-conditioned buildings, then apply the credit modifiers in Table 32.

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

Table 28. Summer average maximum temperatures.

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

Table 29. 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 30. Modifiers for windows

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

Table 31. Modifiers for ventilation

	Credit Modifier
Fully Air-conditioned	+4
Partly Air-conditioned	+2

Table 32. 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 33. CCSI credits for overheating.

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 present overheating performance. Adaptation is more urgent and comprehensive the lower the score.

Some ways of estimating the modifiers used in the previous tables are discussed below.

For window to wall area, using tinted or reflective glazing can reduce the solar gain. To estimate the effect of this, use the following methods.

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 m² window glazing is 75% reflective, the effective window area is $10\ m^2 \times 75\% = 7.5\ m^2$.

If tinted glass is used, calculate as the window area multiplied by (100%-percentage tint/2). So, for example, if a 60% tint is used on a 10 m² window, calculate $10\ m^2 \times (100\% - 60\%/2) = 10\ m^2 \times 70\% = 7\ m^2$.

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 calculated. A calculation method is available in BS 5925 (1980) to estimate the likely minimum air change rates in naturally ventilated buildings. Unfortunately, a simple rule-of-thumb method is not available for this problem. As a rough estimate (from CIBS (1975)) openings on one side only will give 3 ach, and windows 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 in moderate wind conditions.

7.7 Greenhouse Gas (GHG) Emissions

GHG emissions for the heating and cooling of office buildings can be substantial, and vary widely with the building's location, type, and the type of heating and cooling system. There is no simple building energy model simulation tool available for New Zealand office buildings that could sensibly replace the ALF method that was used for the housing assessment. The SEDA Building Greenhouse Rating Scheme for Australia is an example of a suitable type of tool (SEDA, 2000). It rates the GHG emissions of commercial buildings on a 0 to 5 scale, taking into account such factors as climate, building form, HVAC equipment, and energy source. The tool is not available in, or usable for New Zealand in its present form, but (in principle) the tool could be adapted.

The BETARG2 (Building Energy Performance Targets) method is the closest tool to the SEDA tool relevant to New Zealand offices and climate. It calculates energy performance targets and actual documented building energy consumption (not GHG emissions). In the opinion of one of the BETARG2 authors it does not give as good an indicator of energy use as the SEDA tool, is based on outdated information, and does not calculate GHG emissions (Isaacs, 1999). The BETARG2 method relies on a set of climate based modifiers (related to heating and cooling degree days) to predict the performance targets, which are multiplied by the Base Energy Use Indices in Table 34 to derive heating and cooling target energies. The efficiency and fuel type of each appliance could then be used to estimate the GHG emissions.

Building Type	Heating	Cooling	Lighting	HWS	Equipment	Total
Offices Internal Load Dominated (ILD)	175	25	175	10	75	460
Offices Skin Load Dominated (SLD)	240	10	175	10	15	450

Table 34. BETARG2 annual base energy use indices in MJ/m²

Applying BETARG2 to generic buildings gives a wide range of energy use (see Figure 8). Note that for most sites the heating energy makes up almost all the energy use. This disagrees with the results of the simulations in section 4.10, page 18, where for Auckland the cooling-load was approximately twelve times larger than the heating energy, and the actual cooling energy four times larger than the heating energy. BETARG2 appears to give unrealistically low estimates of the cooling energy, and therefore does not appear to be suitable for the CCSI.

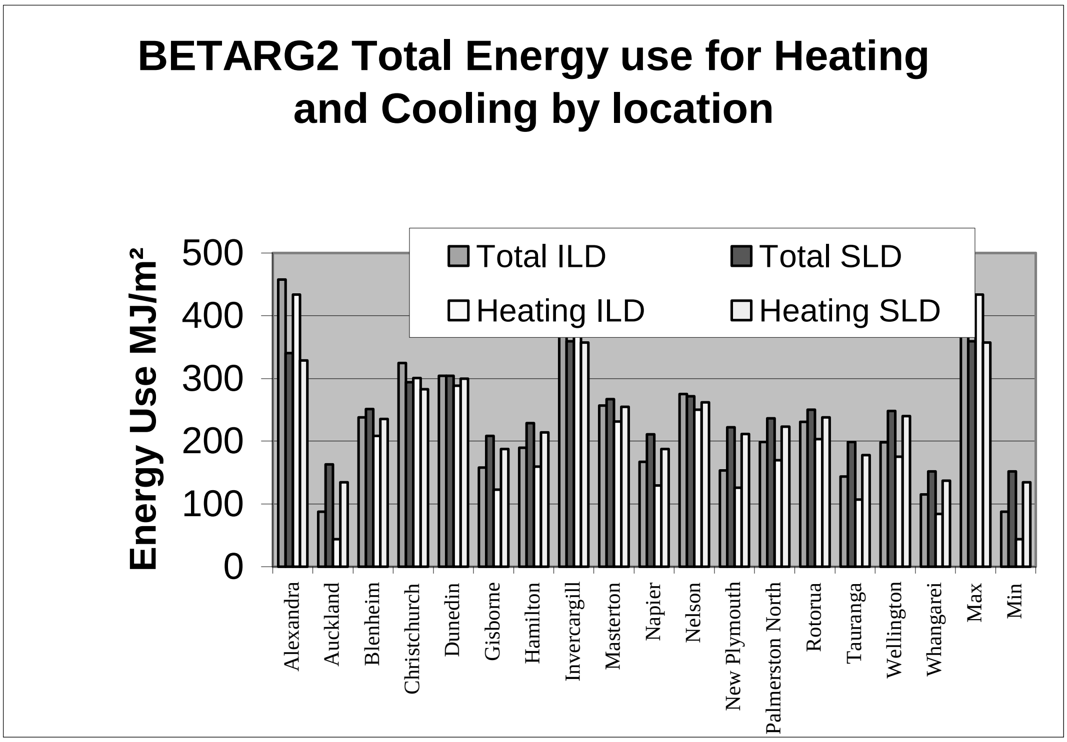

Figure 8. BETARG2 heating only, and total heating and cooling energies by location.

Ideally, the CCSI rating would be based on an estimate of the GHG emissions for the building under ‘normal’ usage. In the absence of a simple and sound methodology for estimating the GHG emissions of New Zealand office buildings, a highly simplified approach is taken. Either calculate the GHG emissions for the actual energy use of the building, or use simple measures based on the climate, building type, and energy source. These two methods are detailed in the following sections.

7.7.1 Rating Based on Actual Energy Bills and Energy Source

The average total energy use for a commercial building is about 250 kWh/m²/year (EGL, 1999). Very poor buildings use 400+ kWh/m²/year, and very good buildings less than 100 kWh/m²/year. Converting these energy ranges to GHG ranges using the marginal electricity emission factor[14] of 0.64 kg CO_2 eq. / kWh (and rounding) gives a range of GHG emissions Table 36. A suggested scale for the CCSI is given in Table 37. The reference level of 0 credits is set at 130-195 kg CO_2 /m²/year, which corresponds to the average 250 kWh/m²/year using marginal electricity. Higher credits are possible for more energy efficient, or less energy intensive buildings, and for those using other fuels such as Natural Gas for water and space heating. The 5 credit rating is reserved for buildings with no GHG emissions for energy use, so they must use solar or other renewable energy sources.

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 35.
4. Assign CCSI Credits according to Table 37.

[14] The marginal electricity emission factor is used as any increase or decreases in electricity consumption is likely to be met by changes in the output of the so-called marginal stations, which are mostly fossil-fuel, thermal power stations.

The main problem with rating on energy bills is that these bills are not readily available on a nationwide basis, so rating all the building stock in a region is not possible. An alternative approach is presented in the next section.

	Emission Factor kg CO_2 equivalent/kWh
Coal	0.36
Natural Gas	0.19
LPG	0.22
Diesel	0.25
Electricity	0.10
Marginal Electricity	0.64

Table 35. Emission factors for major New Zealand fuel sources[15].

kWh/m²/yr	Description	GHG emissions, all electric Kg CO_2 eq. /m²/yr
<100	Very good	0-65
100-200	Good	65-130
200-300	Average	130-195
300-400	Poor	195-260
400+	Very poor	260+

Table 36. Suggested range of energy usage for New Zealand commercial buildings.

GHG emissions, all electric Kg CO_2 eq. /m²/yr	Credit s
0	5
0-30	4
30-60	3
60-90	2
90-130	1
130-195	0
195-260	-1
260+	-2

Table 37. CCSI credit allocations for GHG emissions.

7.7.2 Rating based on Climate and Building Features

Without access to a simple, reliable GHG or energy rating scheme for New Zealand office buildings, the following scheme is suggested as an interim measure. It is designed to categorise buildings according to their GHG emissions, based on the simplest possible data requirements. Water heating is not included separately in the rating, as it makes up only 2% of total energy use for office buildings compared to 35% for houses (Isaacs, Donn, Lee, et al, 1996). Lighting

[15] Fossil fuel emission factors are for direct combustion.

energy has also not been separately rated, as too much detail is required to do this adequately, especially if daylighting is to be accounted for.

This method is intended to rank buildings in their likely order of GHG emissions. It is admittedly highly simplified, but captures the three major factors that influence GHG emissions: energy source, air-conditioning use, and climate zone.

The credit rating scheme for GHG emissions for houses followed a geometric progression, with each credit corresponding to a 1.5 times factor (approx) in GHG emissions. The credit modifiers applied here are intended to give a similar progression for office buildings. The reference level is a non-air-conditioned building in Wellington using electricity.

Start with the base credits for the appropriate building type and climate zone from Table 38. The three zones give an indication of whether the building is likely to be heating-load or cooling-load dominated, or about equal. For a cooling-load dominated building, heating demands are much lower than cooling demands, so there is a large increase in energy use if air-conditioning is used, and a large jump in base CCSI credits. For a heating load dominated building, there is little additional energy required for air-conditioning, so there is a smaller jump in base CCSI credits. 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 38. Regional base credits for heating only and air-conditioned buildings.

Next, add the score for the energy source as in Table 39. Deciding when the energy is, for example, mainly electricity or a mix requires some care. ‘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 39. Credits modifier for energy source.

7.8 Final CCSI weighting

The final CCSI weighting process is the same as that used for houses. Two numbers are presented, one for impacts of climate change on the office building, and the other for the building's GHG emissions. The CCSI for climate change impacts is defined as the average credits from the overheating, tropical cyclones, and the weighted coastal and inland flooding credits as per the CCSI weighting for houses. In this way there is equal weighting for, overheating, cyclones, and flooding. In addition, if the flooding credit is X, the entire rating is X.

The CCSI for GHG emissions is either the figure derived from the actual energy consumption (section 7.7), or from building design factors (section 7.7.1).

CCSI Impacts

	Overheating	___
	Cyclones	___
Inland Flooding Coastal Flooding →	**Flooding**	___
	Total	___

CCSI GHG Emissions

Actual Energy Bills Or: Building design factors →	**GHG Emission**	___

8. APPENDIX: OFFICE BUILDINGS SIMULATION RESULTS

A comprehensive report on adaptation and mitigation strategies for overheating in office buildings was commissioned from Energy Group Limited (Energy Group, 2000), and forms the basis for the CCSI assessment in section 7.6, page 44.

This report investigated the relative effectiveness of several mitigation strategies for overheating on two types of office buildings. Building types were a naturally or mechanically ventilated two-storey office building, and a 10-storey office building.

Air-conditioned buildings were found to maintain adequate temperature control with climate change, providing that the air-conditioning system had adequate capacity.

A number of mitigation scenarios were modelled:

1. Reduce lighting intensity from 18 to 9 W/m^2
2. Reduce transparent window area by 75%
3. Increase ventilation from 5 to 8 ach
4. Scenarios 1, 2, and 3 together

One measure of overheating used in the report is the threshold outdoor temperature at which indoor overheating occurs. This was, on average, 18.8 ºC for office buildings in Auckland, Wellington, and Christchurch. A measure of the effectiveness of a scenario is how much higher this threshold temperature is raised. To maintain a similar pattern of internal temperatures with climate change, the threshold temperature should be increased by the same amount as the climate change increase. So for example, a temperature rise of 0.9 ºC could be compensated for by adopting Scenario 1 of reducing lighting levels (see Table 40).

Scenario	Threshold Temperature	Increase
Base	18.8 ºC	0 ºC
Scenario 1	19.7 ºC	0.9 ºC
Scenario 2	21.7 ºC	2.9 ºC
Scenario 3	20.2 ºC	1.4 ºC
Scenario 4	23.5 ºC	4.7 ºC

Table 40. Threshold overheating temperatures for various mitigation scenarios.

From Table 40 it can be observed that dealing with modest outside air temperature increases of 0.3 to 0.9 ºC (years 2030, or 2070 low end) could be accomplished by reducing lighting intensity levels. The high end 2070 temperature increase of 2.6 ºC could be dealt with by reducing solar gains alone (where feasible), or by any combination of scenarios 1, 2, and 3.

It appears that maintaining existing levels of thermal performance with modest climate change is relatively easy for office buildings. Reducing lighting intensity levels is feasible and cost effective with current lighting technology, and should become cheaper and easier in the future. If temperatures increase by much more than 1°C then improved solar control and ventilation will be required.

9. APPENDIX: HISTORICAL TEMPERATURE PATTERNS

Historical annual and monthly temperature patterns for Auckland and Christchurch are given to provide a basis for comparing the climate change induced temperature changes with normal variations in the current climate. Data was provided by Brett Mullan of NIWA.

Changes in annual mean temperatures expected with climate change are:

Year	Temperature Change
2030	+0.3 to +0.9°C
2070	+0.6 to +2.7°C

Changes in the monthly mean temperatures are similar, with some small seasonal and regional variation (see Camilleri (2000a)).

For Auckland, no single year has had an average temperature more than 1.5°C warmer than the average (>16.6°C), and for Christchurch none more than 1.0°C warmer than the average (>12.7°C). So with climate change, by 2070, the ***average*** annual temperature in both Auckland and Christchurch could be warmer than the ***hottest*** single year under the current climate. The ***coldest*** year under climate change could be as warm as the ***average*** year under current climate.

For monthly temperatures, the changes are not as different from current climate, as there is more variation in monthly average temperatures than annual average temperatures. If the high end, 2070, temperature increase of 2.7°C occurs, then ***every*** month will be warmer than the current ***average***, and half of all months warmer than the ***hottest recorded month***. For more modest temperatures increases, the changes are less startling, but even so, what used to be unusually warm months would become common. For example, with a +0.9°C temperature rise, the average month in Auckland or Christchurch would be warmer than about 85% of all months under the current climate. It is apparent from Table 41 that even with only a slight increase of +0.3°C, the average monthly temperature would be warmer than 75% of all months under the current climate.

Temperature Increase (°C)	Average month warmer than	% chance hotter than hottest month
+0.3	75%	1%
+0.6	80%	1%
+0.9	85%	2%
+2.7	>99%	~20%

Table 41. Average month warmer than given percentage of months under normal climate.

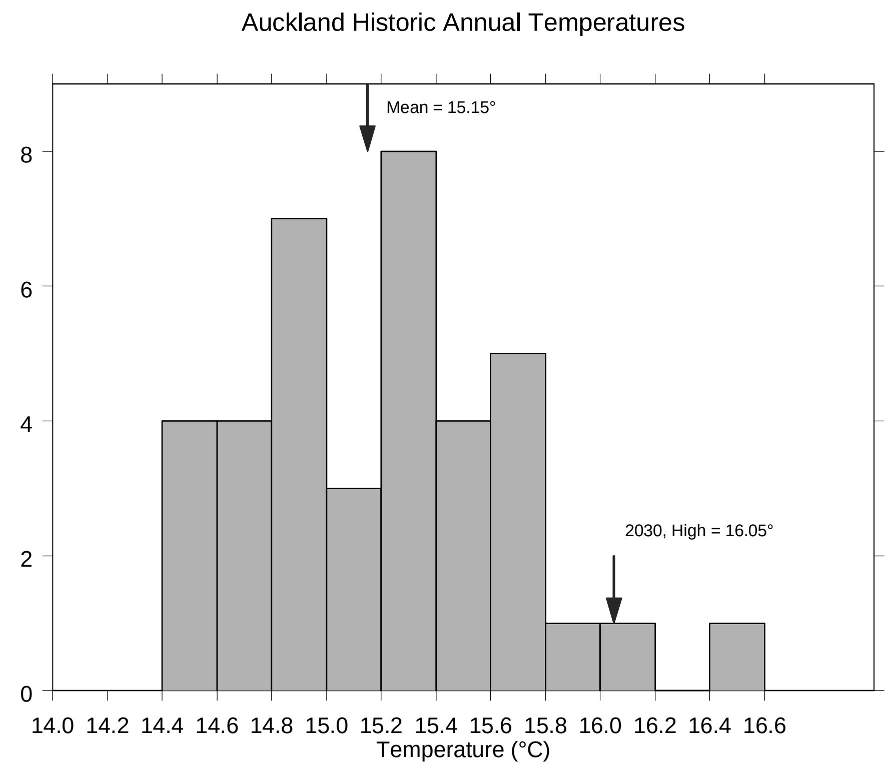

Figure 9. Auckland annual average temperature histogram.

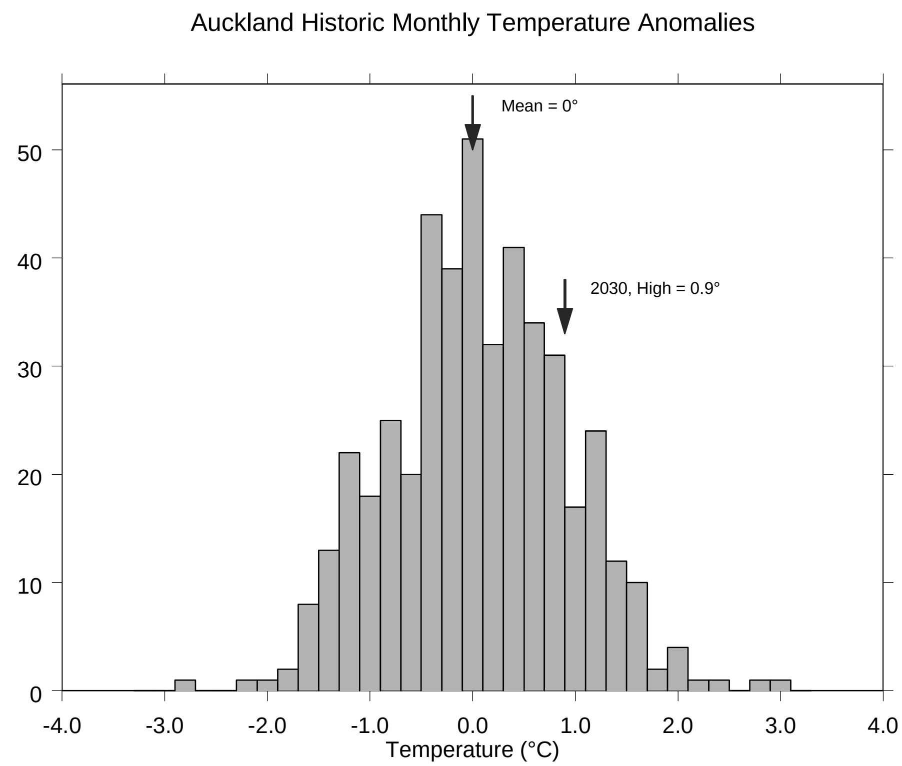

Figure 10. Auckland average monthly temperature histograms.

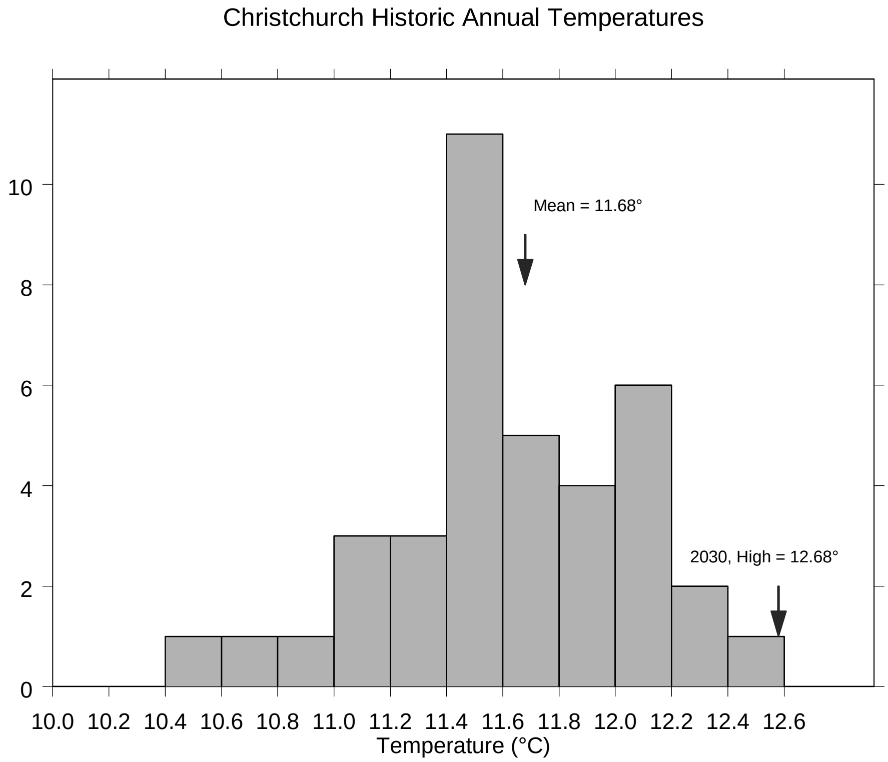

Figure 11. Christchurch annual average temperature histograms.

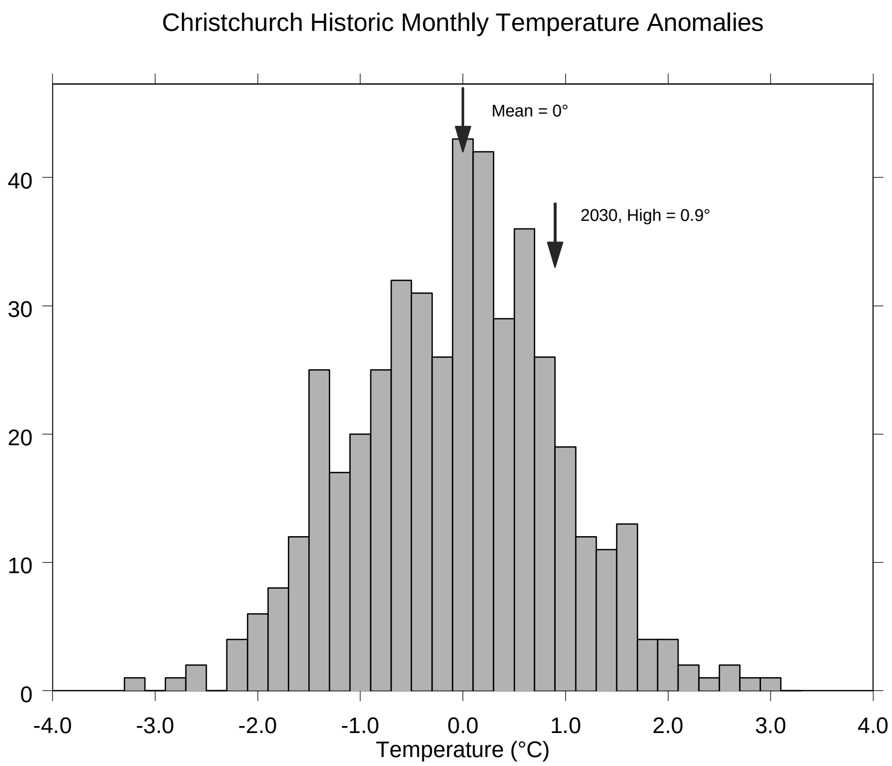

Figure 12. Christchurch average monthly temperature histograms.

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