STUDY REPORT

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Towards Carbon-Neutral and Climate-Adapted Domestic Buildings – Background Document

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Preface

This background document looks at climate change-related building issues. It examines the impacts, and suggests possible mitigation methods (for dwelling in a carbon-constrained manner) and adaptation methods (for dwelling in an altered climate), concentrating on new domestic buildings. The goal is to provide designers/specifiers/building technologists with a range of options on how to achieve low carbon and climate-adapted new domestic buildings.

This document provides the background material to the accompanying BRANZ specification assistance brochure called *Designing Homes for Climate Change* (2006).

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TOWARDS CARBON-NEUTRAL AND CLIMATE-ADAPTED DOMESTIC BUILDINGS

BRANZ Study Report 150 (2006)
Roman Jaques and Agnes Sheridan

REFERENCE

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ABSTRACT

This report looks at climate change-related building issues as related to new New Zealand domestic buildings. It examines climate change-related impacts, and suggests possible mitigation methods (for dwelling in a carbon-constrained manner) and adaptation methods (for dwelling in an altered climate). It provides designers/specifiers/building technologists with a range of options to significantly improve the climate readiness of their buildings while at the concept or design stages. The suggestions/recommendations are further developed into specific design targets in the associated BRANZ specification assistance brochure called *Designing Homes for Climate Change* (2006).

KEYWORDS

Climate change, carbon neutral, adaptation, climate responsive, carbon constrained, domestic buildings.

INTRODUCTION

There is now little doubt that climate change is a real phenomenon that will significantly affect humankind over the next 100 years. Research on climate change is continuing to show that it is inevitable and that society will have to adapt to it. Many of the reasons for climate change have been attributed to humans over the last half century. The latest public IPCC Assessment Report (WHO 2003) stated that "*there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities*".

The built environment in which we live will certainly feel the effects of a changing climate. As such, it is imperative that we take measures to adapt and mitigate our buildings against such impacts now. This background report looks at the impacts, and suggests possible mitigation methods (for dwelling in a carbon-constrained manner) and adaptation methods (for dwelling in an altered climate), concentrating on new domestic buildings. The goal is to provide designers/specifiers/building technologists with a range of options on how to achieve low carbon and climate-adapted new domestic buildings. The documentation for this provision is divided into two parts:

- this background document, which provides generic instruction after exploring key issues and their implications
- design targets in the accompanying specification document, which can be applied to new houses (either detached or attached).

It should be noted that originally this document was intended to provide design and building solutions for a fully 'carbon-neutral built environment'. That is, "*the construction, occupation and reuse/demolition of a building that creates no net contribution of* CO_2 *into the atmosphere*" (from original contract document). However, it was soon realised that this is a near impossible task given today's constraints, even in the case of new dwellings. New buildings only are targeted as it is generally recognised that the changes necessary for almost all existing houses would be uneconomic and impractical. Thus, the new carbon goal became "*designing for a significantly carbon-reduced building solution, in new dwellings*". As for the climate-adapted building-related goals, no changes were necessary from the original contract document.

BRANZ Ltd has some associated and supporting publications that should be read in parallel with this document, if possible. Many of them are downloadable from the BRANZ website (www.branz.co.nz). They include but are not limited to:

- *Implications of Climate Change for the Construction Sector: Adaptation and Mitigation Strategies and Revised CCSI* (Michael Camilleri 2001)
- *Summertime Overheating in New Zealand Houses – Influences, Risks and Mitigation Strategies* (Roman Jaques 2002)
- *Implications of Climate Change for the Construction Sector: Houses* (Michael Camilleri 2000)
- *Climate Change Adaptation* (Michael O'Connell and Rachael Hargreaves 2004)
- *Coping with Climate Change* (BRANZ *Bulletin* 414).

AIM

This report forms part of a levy contract entitled *An Integrated Response to Climate Change Mitigation and Adaptation*. The outputs include: a public-friendly calendar on climate change for 2005, a conference paper from the Sustainable Building Conference (SB05), this background information paper, and a downloadable building specification for climate-ready residential building.

The aim of this background document is to identify flexible, integrated climate change 'living solution' responses for the building industry by exploring options to deliver:

- a carbon-neutral built environment (i.e. *mitigation* techniques)
- an adapted built environment in an already altering climate (i.e. *adaptation* techniques).

This document provides background information to the associated building specification entitled *Designing Homes for Climate Change* (Jaques 2006), which provides practical targets for those influencing the design process. The focus here is on new domestic buildings – specifically detached or attached domestic buildings. The goal is to provide 'carbon-constrained' and 'climate-adapted' living solutions that are vastly better than today's standard construction and living practice. The objective is to provide as many win-win solutions for both challenges, wherever possible.

What this document **does** provide is:

- recommendations which can be developed into more detailed specifications based on materials, systems and approaches that are not radically different from what is currently available today, all at a reasonable cost
- practical approaches that are proven and available today
- a selection of choices that don't severely compromise other aspects of sustainability
- encouragement for integrated initiatives.

What this document **does not** provide is:

- financial aspects and incentives for becoming climate change adapted and carbon-constrained
- detailed passive solar design strategies and analysis
- information on issues external to the house site such as local planning issues, urban density, edible landscape concepts, community living and urban design issues in general.

All these issues are considered beyond the scope of this document.

METHODOLOGY

A fundamental question in a document of this nature is: where is an appropriate boundary to determine just what issues fall within its scope? Does the 'dwelling' finish at the building's physical perimeter, at the section boundary, or should it extend to its neighbourhood and or/community? It was decided that, given the construction focus and the fundamental importance of geographic location, the scope should be mainly concerned with the building itself, with the exception of the transportation aspect.

To a large extent, the issues of adaptation and mitigation techniques can be dealt with independently, since their focus is quite different and usually complementary. One deals with the influence of buildings on climate change, the other with the effects of climate change on buildings. Both issues deal with a subset of sustainable living. This document has therefore divided the two aspects of climate design into **Section A: Towards Carbon-Neutral Dwelling** and **Section B: Towards Climate-Adapted Dwelling**. These groupings reflect the (mostly) distinct design and construction aspects involved in each.

The intent of this document is not to extend the research in the field of climate-adapted/mitigated domestic buildings. Rather, its aim is to assemble existing data, information, research findings and knowledge on climate-related building factors and provide clear, practical solutions which a designer can work with and a specifier can be informed from. This document provides the reader with an overview of what to target, how to achieve it, and what to look for in pursuit of designing and constructing more 'climate change ready' domestic buildings.

DEFINITION OF TERMS

Some of the concepts used in this report are not well recognised nationally, or not defined internationally, or are simply specific to this report. Their (suggested) definitions are included below, but these are in no way meant to be definitive. However, they are necessary to better understand the scope of the document.

Climate-adapted buildings: Designing and constructing buildings to prepare them for the predicted effects of climate change impacts, resulting from increased flooding and cyclones, higher temperatures etc. This is the impact of climate change on buildings.

Climate-mitigated buildings: The ways and means of preparing a building to lessen its impacts on climate change, through its use of fossil fuels during the building's lifetime. This concerns the impact buildings have on climate change.

Carbon-neutral buildings: Buildings that create no annual net CO_2 emissions from their operational-related energy use and material requirements, while also having modest energy needs in their day-to-day operations. This report recognises that there is more to specifying and assessing carbon-neutral as an individual entity. The wider issues of sustainable building must be recognised and properly integrated.

DISCUSSION OF TERMS

There is no formal definition or concerted agreement on what it means for a building to be 'carbon-neutral'. A general definition might be: "*The construction and occupation of the building creates no net contribution of CO_2 to the atmosphere*". This definition can be refined to something more descriptive such as that proposed by BRE's *Building a Sustainable Future* (1996) guidance document, which defines a zero CO_2 (i.e. carbon-neutral) house as one that:

"*… creates no net emissions of CO_2 on an annual basis. This means it must obtain its heat and power from renewable energy. It may do this by buying electricity on a green tariff … If the house makes use of any non-renewable energy sources, it must have its own renewable energy system of sufficient capacity such that, during any year, it can export enough renewable energy to compensate for the CO_2 emissions associated with other important energy*".

A well-respected US publication (*Environmental Building News* 2005) defines a climate-neutral building similarly as one which over a year's operation "*offsets emissions equivalent to the amount emitted through the source energy that powers the building*". This 'climate-neutrality' can be achieved either through on-site electricity generation production or the purchase of renewable energy credits supporting the generation of off-site renewable energy. Unfortunately, both these definitions can lead to fundamental environmental compromises, where even the most resource inefficient building can achieve carbon-neutrality by purchasing a balance of renewable energy credits. The intent of this background document is to provide a more holistic response by providing design approaches to minimise the resource needs in the first instance, without compromising other sustainability aspects considerably. This philosophy is reflected in the definition adopted for this document.

What is a climate-adapted building? The UKCCIP report by Willows and Connell (2003) states that climate adaptation is the "*outcome of a process that leads to a reduction in harm or risk or harm, or realisation of the benefits associated with climate variability and climate change*". Previous studies by BRANZ have stated that "*an adapted building is a structure that can cope with many different climatic scenarios*" (O'Connell and Hargreaves 2004). In summary, climate-adapted buildings are those which are built to withstand the predicted negative impacts of climate change and also those which can maximise any positive impacts of a change in climate. Important aspects of climate adaptive buildings are: resilience, resistance and adaptive capacity (Wilson and Burtwell 2002).

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Section A: Towards carbon-neutral dwelling

Building a 'carbon-neutral' dwelling using currently available methods of construction and operation is an immense challenge. Even in the considerably more developed international building scene, there is currently no single dwelling that can be classified as 'carbon-neutral' as defined in this report. Given the lack of real-world precedents for carbon-neutral dwellings, this background document tends towards the more realistic goal of providing "*design assistance strategies to considerably reduce new dwellings' lifetime carbon footprint*".

Essential to the carbon-constrained philosophy is the idea of energy efficiency and energy conservation, to minimise energy loads as much as practicable, no matter what the fuel source is. Encouragement needs to be given to designs/living solutions that promote this philosophy. This deters the profligate energy user who would otherwise be able to neutralise their emissions as long as they have sufficient renewable-based generating capacities or carbon-sinking abilities. Other parallel and supporting strategies which should be adhered to are:

1. There should be a concerted effort in the building's design and operation to ensure that the best use of passive and 'low tech' solutions be used, where possible.
2. Encouragement should be given to renewable fuel sources, which are site-specific or regional-based (i.e. supporting distributed power supply).
3. The solutions suggested should be proven off-the shelf technologies and materials, recognising their lower inherent risk.
4. The design solutions suggested for the carbon-neutral aspects of the dwelling should not compromise those suggested for the climate-adapted/mitigated building solutions.
5. The costs in providing these carbon-constrained solutions should not be prohibitive.

Only key technical (i.e. physical) building-related aspects of detached and attached dwellings are examined in this section on carbon-constrained dwellings. The specific issues examined are:

- **thermal performance** – designing for summer cooling as well as winter heating
- **major appliance selection** – covering hot water heating, space heating and cooking
- **lighting –** luminaire choice and placement
- **construction materials** – from the cradle to the grave, and finally
- **geographic siting** – of the dwelling and the resulting transport needs.

1. THERMAL-RELATED CARBON

1.1 Introduction

The science of good thermal house design appropriate for New Zealand conditions is well established but not well understood or practised. It is beyond the scope of this document to describe in detail the principles behind, and thermal performance results from, good passive design. This is best left to 'how-to' documents such as *Design for the Sun* (working and reference manuals) (Richards 1994A and Richards 1994B respectively) and appropriate thermal modelling software such as SUNREL.[1]

For a comprehensive examination of a system such as a house, where there are complex interactions between the building and its occupants, simpler design guidelines providing 'rules-of-thumb' are to be avoided if possible or used with a degree of caution. The reason for this is "*Rules of Thumb often hide more about a subject than they help explain*" (Donn 1987). However, it was considered necessary in this background document to broadly examine some key design aspects of thermal cooling and heating.

1.2 Heating aspects

The top three design priorities, which establish the relative importance of key passive design issues, are:

PRIORITY 1: INSULATE WELL BEYOND THE REQUIREMENTS OF THE NEW ZEALAND BUILDING CODE (NZBC)

PRIORITY 2: GLAZE WITH CONSIDERATION FOR THE SUN

PRIORITY 3: ADD THERMAL MASS WHICH GETS EXPOSED TO THE SUN.

Each of these issues will be examined briefly.

INSULATION

The overall heat loss rate in a house is fundamental to determining the potential annual energy consumption levels (Richards 1994B). The rate of heat loss is measured in watts per degree centigrade (i.e. W/^{o}C) and is climate independent. What is a good performance heat loss target to move towards a carbon-neutral dwelling? There are several approaches to this internationally, with no one 'correct' answer and set target levels sometimes quite arbitrary. Renowned low energy designers, Robert and Brenda Vale, set the following target for their zero CO_2 dwelling specification for the UK case:

> ***A fabric (i.e. whole building) R-value resulting in a 60% reduction of the space heating demand, compared to the current UK Building Regulation requirements.***

Obviously, translating the Vales' suggested R-values for the New Zealand situation has limited use, due to our differing code requirements, comfort expectations and this country's comparatively warmer climate.

1 Available as a download from www.eere.energy.gov

With the advent of SNZ PAS 4244 (Standards New Zealand 2003) for lightweight construction and *Designing Comfortable Homes* (CCANZ 2001) for heavyweight construction higher insulation specification, the benefits of good passive solar design are clearly displayed in an easily digestible format. Both documents provide solid specification guidance on the selection of ‘better practice’ and ‘best practice’ insulation levels that are well above the minimum (and inadequate) requirements of the NZBC through simple schedules. The schedules are all underpinned by thermal modelling. Even the ‘best’ levels for both documents are set at what can be constructed today without relying on radically different construction techniques.

SNZ PAS 4244 recognises the significant climatic differences in New Zealand by dividing the country into three climatic zones. The cooler the climate, the more insulation is specified. The climate zones are:

- warm climate zone – Auckland and Northland
- cool climate zone – all of the North Island not covered by the warm climate zone
- cold climate zone – all of the South Island and the Volcanic Plateau.

A summary of the best practice levels, their associated R-values and heat loss values required for the three climate zones is displayed in

Table 1 below.[2]

Table 1: Construction R-values and performance indicators (after SNZ PAS 4244)

DESCRIPTOR	NZBC compliant: cold climate	Best practice: warm climate (SNZ 4244)	Best practice: cool climate (SNZ 4244)	Best practice: cold climate (SNZ 4244)	Near carbon-neutral
Annual space heating (kWh/yr)	3000	1110	990	1140	700
Annual amount of CO_2 (in kg) for an all electric set-up[3]	1350	500	446	513	315
50 year CO_2 savings cf NZBC requirements (tonnes of CO_2)	0	25	22.3	25.7	15.8
Indicative space heating saving cf NZBC	0%	63%	67%	62%	77%
Roof (R-value in $m^{2o}C/W$)	2.5	3.3	3.3	3.5	5.0
Wall (R-value in $m^{2o}C/W$)	1.9	2.6	2.6	2.6	3.0
Floor (R-value in $m^{2o}C/W$)	1.3	3.1	3.1	3.1	3.5
Window (R-value in $m^{2o}C/W$)	0.15	0.31	0.43	0.48	0.48
Indicative whole building heat loss values ($W/^oC$)	400	215	188	179	162

The near carbon-neutral level is added to the
Table 1 thermal insulation value variations for the building elements. It extends the previous best practice values, yet is still able to be constructed using non-radical methods. It was chosen as it corresponds with dynamic simulation modelling which BRANZ has done on zero and low energy houses. Specific

[2] The product R-values necessary to achieve these constructional R-values are diagrammed within SNZ 4244, and for heavyweight construction are diagrammed within CCANZ (2001).

[3] Assuming electricity at the margin mix, having a CO_2 intensity of 0.45 kg CO_2/kWh.

construction targets for the near carbon-neutral design solutions are provided in the associated *Designing Homes for Climate Change* (Jaques 2006) guidance document.

It is likely that for well-designed passive solar houses that have a reasonable level of thermal mass and 'best practice' insulation levels, very little space heating will be required for warmer/higher sunshine hour regions in New Zealand to maintain wintertime comfort. It is also likely that for well-designed passive solar houses that have a reasonable level of thermal mass and near carbon-neutral insulation levels, space heating will be required in only the cold climate zone (i.e. Zone 3). It is suggested that, in the specification of insulation levels, the 'best practice' level should be aimed at as a minimum, but with a preference for all buildings to meet the near carbon-neutral R-values.

Whole building heat loss rates in
Table 1 are provided for more design flexibility – i.e. elemental trade-offs can be made between building elements without compromising the thermal performance of the design, if required.

When choosing the *type* of insulation to ensure a low carbon footprint, the current New Zealand carbon intensity information is incomplete. Specifically, the data for mineral fibre and rock wool are unknown. However, embodied energy figures can be used as an indicative proxy for CO_2 emissions for many building materials. It has been shown in a New Zealand study (Jaques and Cox-Smith 2004) that the embodied energy (and therefore it may be assumed embodied CO_2) contribution of insulants is very small when examining whole life-cycle energy contributions. This agrees with other international information. As the well-respected *Environmental Building News* (2005B) states "… *no matter what type of insulation (is) used, if used appropriately, its environmental benefits over a building's life will almost certainly outweigh any negatives – and dwarf any environmental differences among the alternative materials*". In essence, the main design-related issue in choosing the type of insulation is ensuring that the overall rate of heat loss is sufficiently low enough to guarantee the efficient use of solar energy and thereby minimise the lifetime environmental (CO_2) impact of insulation. Thus, its performance in-situ is central to its overall carbon impact.

In New Zealand, the Environmental Choice programme provides a guide for consumers who want to purchase products that are better for the environment (www.enviro-choice.org.nz). BRANZ recommends that Environmental Choice certified products should be selected if there is a choice between insulation products providing the same insulation level. This is because the certified product guarantees the quality and in-situ performance of the product, and ensures it was manufactured in a lower impacting manner.

When super-insulating a dwelling, its thermal integrity and therefore performance can be easily undermined by careless design and in-situ installation. Essential to its good installed performance are aspects such as:

- designing for the minimisation of thermal bridging, especially at elemental junctions (e.g. wall-ceiling and wall-to-floor) and use of extra stud work
- careful insulation of stud corners, wedge spaces and thresholds
- correct installation so no air gaps or cold bridges result between studs and dwangs
- insulation of external doors, which although not usually counted as part of the thermal envelope, should be.

GLAZING

The appropriate sizing, amount, placement, orientation, shading and construction of the glazing system are critical for good low carbon design. For the proper sizing, amount, placement, orientation and shading, the rules of passive solar design described the two *Design for the Sun* manuals (Richards 1994A and 1994B) should be followed.

Following on from the insulation requirements, it is necessary for the dwelling to be provided with double glazing to achieve the required 'best practice' target for whole house heat loss. Whether the chosen double glazing is lower performance (e.g. thermally unbroken aluminium frames), or higher performance (e.g. PVC framed with low-e coatings and argon-filled), depends on what trade-offs are going to be made with the other building elements.

When choosing the most appropriate double glazing system, its lifetime ability to insulate should be weighed against its lifetime durability and maintenance requirements. In the choice of the highest insulation value possible, the WERS star rating system (refer www.wanz.org.nz/star_charts.htm) should be consulted. However,
Table 2 summarises generic R-values for various glazing types. For more precise values, the manufacturer should be asked to supply whole window R-values, rather than centre-of-pane R-values.

Table 2: Common whole window R-values

Type of glazing and framing	R-value (generic)
Single clear (any frame)	0.15
Double glazing with thermally **unbroken** aluminium frame	0.26
Double glazing with thermally **broken** aluminium frame	0.31
Double glazing with composite frame	0.26
Double glazing with composite frame, low-e	0.31
Double glazing with PVC or wooden frame	0.36
Double glazing with PVC or wooden frame and low-e	0.48

For comparative durability of window frames, there is no up-to-date comparative life-cycle information available for the New Zealand case which takes into account such issues as the higher maintenance of timber, the recyclability of aluminium etc. However, the UK preference (BRE 2000), in terms of life-cycle embodied CO_2, is for either:

- pre-treated softwood frames, double glazed, painted inside and out, or
- durable hardwood frame, double glazed, painted inside and out.

How closely this information matches the New Zealand situation is unknown, so it should be treated as an indicative guide only.

THERMAL MASS

There are three types of thermal storage materials – solid, liquid and phase change. Solid materials include masonry derivates such as concrete, brick and ceramics, and can often be incorporated as part of the building structure (Richards 1994B). Liquid materials are thermally more effective than the solid materials, due to their ability to store more than twice as much heat energy as most masonry materials. Phase change materials are usually salt derivatives. They are thermally the best alternative, as they hold the surface temperature constantly near the desirable temperature and are able to store considerably more heat per unit volume and weight than either the solid or liquid options.

As stated in SNZ PAS 4244 (2003), the simplest and most cost-effective form of heat storage uses heavy materials in the floor (typically a concrete slab) to smooth out temperature extremes. Thermal mass is most effective if it is located within the northern aspects of the home and in areas where there is more sunlight. Although it can be incorporated into any surface of the home, it is twice as effective if it receives direct sun rather than diffused rays. The optimum amount of thermal mass is complex to calculate and is dependent on the other passive design features such as insulation levels, local climate, window orientation and size. Due to this complexity, specifics should be left up to the designer and a suitable computer program such as SUNREL. However, guidelines in *Design for the Sun* (Richards 1994B) state:

- mass needs to be radiated with direct sunlight, although diffuse is possible but only half as effective
- the *mass* of the area is the most important issue, rather than the *volume*
- too much mass makes it too difficult to heat up in the morning – too little mass reduces comfort and energy savings, and results in insufficient thermal capacity
- insulate the outside of the mass, between the mass and the outdoors.

If the design utilises a slab-on-ground foundation, the slab must be well insulated. This means that both the perimeter and the underside of the concrete slab should be insulated with 50 mm of high density (i.e. at least 24 kg/m^3) polystyrene. If the ground underneath the slab is damp, then the heat lost through the underside of the slab can be substantial. The slab must work in combination with the sun for maximum benefit. Ideally, the area of hard surfaces (i.e. uncarpeted areas) exposed to the sun should be maximised. Options include patterned or painted concrete, slate, tile or brick. The colour of the hard surfaces can be dark, but not black, otherwise overheating will result. The optimum insulated slab thickness is around 100 mm – 150 mm (Richards 1994B).

Other types of passive solar design options that examine different types of mass configurations are: isolated gain, indirect gain, direct gain. They are detailed in *Design for the Sun's* more technical reference manual (Richards 1994B).

1.3 Cooling aspects

Just how significant will the climate change-related temperature increases be for detached and semi-detached residences in terms of increasing the risk of overheating in the near future? Although occupant overheating is dependent on many factors – such as the air temperature, mean radiant temperature, air velocity, humidity, clothing insulation etc – the default indicator often applied is air temperature, as it is seen as the most important comfort factor.

The estimated increase in the number of days with a maximum air temperature exceeding 25^{o}C for four geographically separate cities in New Zealand is shown in Table 3 below:

Table 3: Days where maximum temperature exceeds 25^{o}C (after Camilleri 2000)

Region	Now	2030	2070
Auckland	20	25–37	31–81
Wellington	3	4–7	5–21
Christchurch	26	29–36	32–64
Invercargill	2	2–3	3–11

Note that the actual temperature inside a building will differ from the external temperature for both physical and occupant-related reasons. However, a fair assumption is that when the external temperature exceeds 25°C, the internal temperature also exceeds 25°C, even if large amounts of ventilation are used (Camilleri 2000). Thus, it can be reasonably assumed that the predicted amount of uncomfortable temperatures in the near future for New Zealand will be considerable.

Table 3 shows that the uncomfortable periods for Auckland and Christchurch are enough to create a summer 'cooling season' lasting about a month within the next 20 years. As stated by Camilleri (2000), this level of prolonged summer discomfort is unlikely to be tolerated by most home owners, who will be forced to take mitigation measures. The mitigation measure most likely be taken is installing air conditioning – and thereby increasing the green house gas emissions as a result. Some design strategies to minimise the necessity to resort to air conditioning dwellings will be overviewed here.

The ability of a dwelling to minimise year-round overheating is an integral part of the passive solar design. Only the essentials of designing to minimise cooling requirements will be given here as technical details are best left for manuals, such as the comprehensive *Design for the Sun* reference manual (Richards 1994B) and the more general Australian *Your Home* technical manual (Reardon 2005). Although these guidance documents will aid designers to select appropriate measures for their particular needs, it is strongly suggested that these be used in concert with dynamic simulation programs, such as SUNREL. This is because of the complex thermal nature of domestic buildings.

A recent edition to the growing body of design knowledge on good passive cooling is the Faber Maunsell design guidance document (Orme and Palmer 2003). Although produced for the UK market, many of the design ideas can be applied to the New Zealand situation – and have been adapted for this overview. In it they state that "… *it is important to consider the basic principles that contribute to overheating. The first and most important factor is that increasing the insulation levels of houses means that heat cannot easily escape from the internal space … during the summer this situation can lead to overheating. These heat gains will increase the temperature of the air in the space and fabric of the building unless they are exceeded by the losses of heat from the house*".

As a house becomes more highly insulated the balance of heat flows becomes very finely balanced.[4] As the external temperature and solar radiation change throughout the day, the external and internal heat flow changes with time. Thus, the thermal mass can represent either a heat loss from the space, when it is cooler than the air in the room, or a heat gain when it is warmer.

Control of solar heat through windows is vital. Westerly orientated windows should be carefully sized to ensure that overheating when the house is already warmed does not occur. The hierarchy of effective window shading systems is (in order of best to worst): external shading (potentially reducing 95% of incoming solar heat), mid-pane (potentially reducing 43%) and finally internal shading (potentially reducing 17%) (Orme and Palmer 2003). A more detailed comparative summary is displayed in Appendix A.

The following overheating controlling techniques (which work for most house types) should be used in combination if possible, for maximum effect. These techniques will reduce the potential to overheat, but only if they bring about a significant decrease in solar heat gains (Orme and Palmer 2003).

VENTILATION

[4] It is suspected that this aspect is often overlooked by the some of the design community in New Zealand.

The volume of cooler air flow supplied and the timing of the ventilation is critical. Generally, the natural ventilation would be provided by one, or a combination, of the following:

- window openings
- purpose-designed vents in the façade, or
- passive ventilation stacks.

Night-time ventilation is essential to remove heat from the thermal mass of the house and it will even provide some control in thermally lightweight houses. It needs to be of the order of 10 air changes per hour on average during the night-time to be effective. Controlling the ventilation is important to prevent over-cooling but windows must be openable, usable for both stack and wind-effect, while capable of allowing a high volume flow of air. There are a number of design tools that can help the designer achieve the requisite air change rate of 10 ac/hour. For details and guidance, consult Dols and Emmerich (2003).

THERMAL MASS

- Providing sufficient thermal mass to control temperature swings is advisable, but will not be wholly effective without night-time ventilation.
- Care must me taken not to de-couple thermal mass with surface finishes, if its sink properties are to be utilised.
- Whatever material is used to provide the thermal mass, it should have sufficient surface area. The design should also allow for the free flow of air over its surface as the heat flow is directly related to the surface heat transfer coefficient, temperature difference between the room air and the surface of the material.
- Increased thermal mass without night-time ventilation for cooling will not reduce the number of overheating hours. In fact, it may increase the number of hours of overheating.
- It is vital that cooling of the thermal mass is provided and this cooling is best provided by passing cooler night air through the house.

CASUAL GAINS

Reducing the casual gains from lights and appliances will reduce the overheating in areas where they are concentrated – typically the kitchen. Overheating in kitchens may be severe and special care must be taken to reduce casual gains and provide controllable ventilation. These can be done through:

- reduction – limiting the size and number of appliances and using only those that are highly efficient (e.g. the replacement of a gas hob with an induction hob)
- removal – through passive measures if possible (e.g. provision to vent the fridge condenser to the outside of house).

1.4 Recommendations

Designing to ensure a comfortable internal temperature year round requires good planning, careful design and preferably the use of a dynamic thermal modelling program, such as SUNREL. However, the basic principles are:

FOR HEATING

1. ***Insulate to well above the requirements of the NZBC****. It is recommended that, as a minimum, the whole house heat loss values should be not greater than:*

   a. *220 W/^{o}C for Climate Zone 1 (for climate zones as defined in SNZ 4244)*
   b. *190 W/^{o}C for Climate Zone 2, and*
   c. *180 W/^{o}C for Climate Zone 3.*

   If possible, however, the preference is to have a whole house heat loss value that is not greater than 165 W/^{o}C for ALL climate zones.

2. ***Glaze for the sun.*** *Choose the highest R-value rated double glazing system possible, as it is likely that this will dictate the overall embodied CO_2 impact of the glazing element. Ensure that the whole window R-value figure is given, rather than the centre of pane, for comparative purposes.*

3. ***Add thermal mass which gets exposed to the sun.*** *As a minimum, ensure that the slab-on-ground is used for thermal storage (i.e. receives direct sunlight) and is well insulated with at least 50 mm of high density polystyrene both underneath and around its perimeter.*

FOR COOLING

It is recommended that a variety of design strategies should be adopted to ensure that overheating is kept to a practical minimum, while not compromising (but supporting) other facets of passive solar design. Specific design strategies and construction details should be explored in documents such as *Design for the Sun* (Richards 1994B) and computer simulations such as LOOP (Dols and Emmerich 2003), if possible. However, the basic design principles are:

- ***Good solar control for windows:*** *with the effectiveness of shading systems (in order of best to worst) being: external shading, mid-pane and finally to a much lesser ability, internal shading. Westerly windows are to be used sparingly.*
- ***Adequate ventilation:*** *provided by one, or preferably a combination, of the following: window openings, purpose-designed vents in the façade, and passive ventilation vertical stacks. The idea is to ensure that stack ventilation can be used for breezeless days. Window openings must be large enough to provide at least 10 air changes per hour and be controllable to prevent over-cooling in the night-time.*
- ***Effective thermal mass using heavyweight building materials****:*
  - *provide sufficient mass for controlling temperature swings while ensuring night-time ventilation for cooling can be used*
  - *it should have sufficient surface area and the design should allow for the free flow of air over its surface*
  - *take care not to de-couple thermal mass with surface finishes, if its sink properties are to be utilised.*
- ***Control of casual internal heat gains through****:*
  - *reduction – limiting the size and number of appliances and using only those that are highly efficient*
  - *removal of sources – using passive measures if possible i.e. a provision to vent the fridge condenser to outside of house, using stack effect.*

2. ENERGY-IN-USE-RELATED CARBON

2.1 Introduction

What is the magnitude of typical domestic CO_2 emissions resulting from energy end uses in New Zealand? BRANZ estimates that energy use in New Zealand homes is mainly met by electricity and natural gas. On average, a typical home consumes about 6,700 kWh of electricity and 2,400 kWh of gas each year. This equates to 3,015 kg of CO_2 emissions from electricity and 360 kg of CO_2 emissions from gas.[5] Although other sources, such as coal and wood, have direct CO_2 outputs their energy input is small compared with gas and electricity for most end uses.

The typical CO_2 emissions for selected electrical household appliances, derived from BRANZ Household Energy End Use (HEEP) data, can be seen in Figure 1: The most substantial CO_2 emissions derive from hot water heating. Other appliances that have significant CO_2 emissions are the electric 'oven' (actually the hob and the oven combined), electric heater, fridge, washing machine and the lighting. Ideally, *all* appliances should be closely examined in terms of their energy (and therefore CO_2) contributions. This is common practice in the setting up of any off-the-grid or grid-tied systems, where appliance power rating and typical daily usage are rigorously examined as part of the overall energy management strategy. Since the focus for this report is on design-related aspects of CO_2, only the non-chattel appliances will be examined. The 'exception' to this is lighting, which will be considered as a non-chattel even though it can be seen as either, depending on construction.

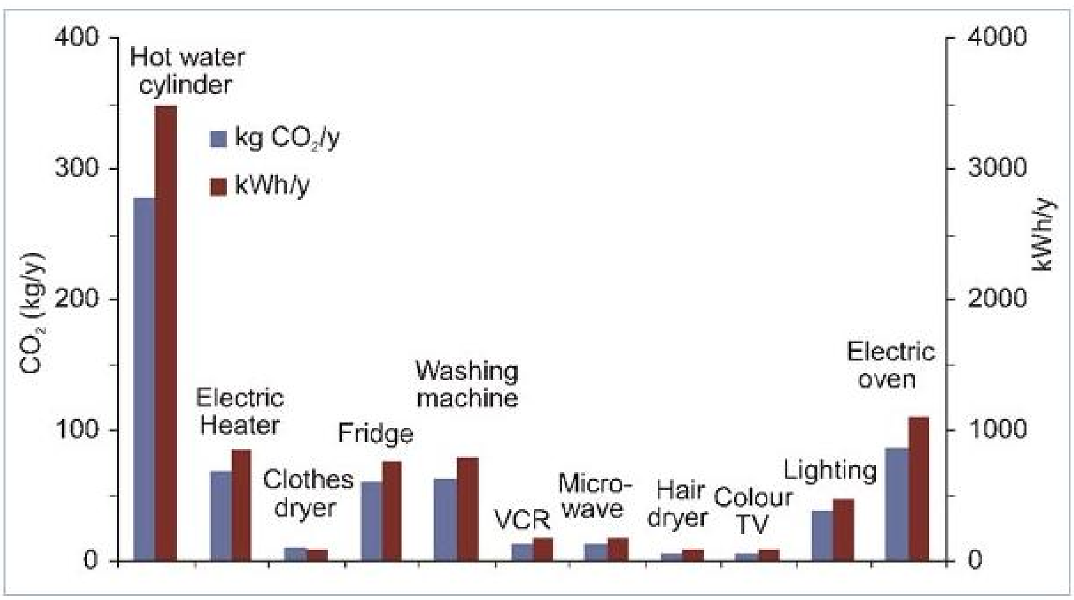

Figure 1: Typical CO_2 emissions and energy usage for selected electrical household appliances
(Source: NIWA website)

[5] Based on marginal emission rates for electricity (at 0.45 kg/CO_2/kWh). Note that the electricity emission figure varies according to the year of production, reflecting New Zealand's ability to meet its increasing electrical needs with renewables.

The carbon implications of using the hot water cylinder, the space heater, lighting and the electric oven/hob will be assessed individually. For examination of the carbon implications of the remaining appliances, web-based resources such as http://search.energyrating.gov.au are suggested.

2.2 Hot water heating

The CO_2 emission quantities for various hot water heaters are shown in Figure 2 below (adapted from Camilleri 2001). All figures are indicative only and both off-peak (average) as well as peak electricity CO_2 emissions are displayed. The range in the CO_2 emission factors for the various fuel types and the efficiencies of the appliances are detailed in Appendix B. It should be recognised that single issue examinations such as this gloss over other important product details. For water heaters, this means that differing heat capacities, the local availability of fuels (such as reticulated gas), heat-up rates, initial and ongoing financial costs, etc, are not considered. However, the information detailed here is targeted for comparative assessment for the carbon-conscious designer.

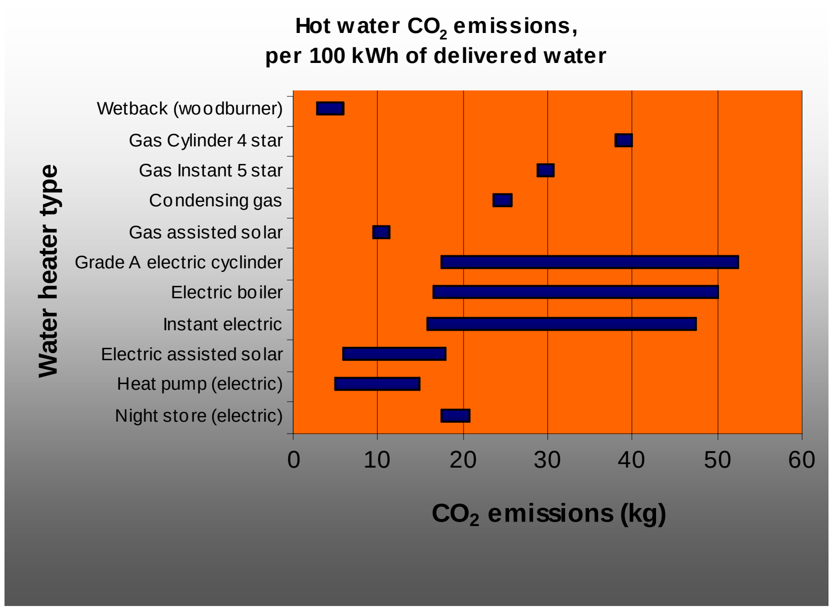

Figure 2: CO_2 emissions per delivered unit of hot water

As can be seen in Figure 2, there is a vast range in the carbon intensities of the various hot water cylinders (HWC). The most carbon-efficient HWC is the wood fuelled wetback with the least efficient being the commonly installed Grade A electrical cylinder. The most polluting HWC is approximately 17 times the least polluting!

Note that less common forms of water heating, such as thermal ground bore and ground heat source (as used in Rotorua), have not been examined here. Although no studies of their comparative CO_2 emissions per kW delivered could be sourced, it is expected that they would fall in the range between the gas-assisted solar and the wetback wood burner.

Naturally, the carbon-efficient water heater needs to be connected to an effective plumbing system as well. Thus, fittings such as low flow shower roses and tap-ware (in high/mains pressure systems only), should be installed if possible. These reduce the water use significantly, while not affecting performance and utility.

2.3 Space heating

The CO_2 emission factors for various space heaters are shown in Figure 3 below (adapted from Cammilleri (2001) and Russouw (1997) and the Ministry for the Environment (2005)). All figures are indicative only, with ranges showing both off-peak (average) as well as peak electricity CO_2 emissions. As for the hot water heater section, the same parameters operate, in terms of CO_2 emissions factors, the indicative nature of the figures and the other issues that need to be considered in addition to the carbon issues.

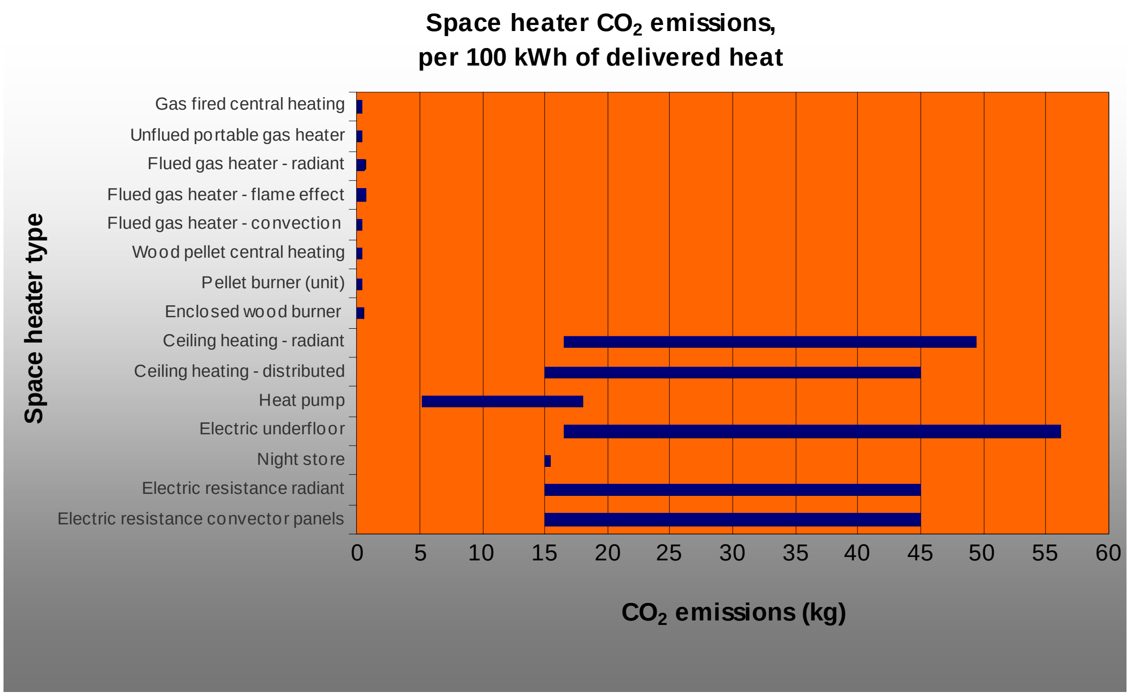

Figure 3: Space heater CO_2 emissions per delivered unit of heat

As can be seen from Figure 3 there is a substantial range in CO_2 emissions, with the lowest emission heater types being wood or gas-fuelled. The most CO_2 polluting space heater options are electric underfloor heating and the radiant-type ceiling heating, which emit 40 and 33 kg CO_2 per 100 kWh (peak) respectively. The heaviest CO_2 polluting space heater is 110 times the least polluting!

Note that less common forms of space heating, such as the thermal ground bore, ground heat source, solar thermal and transpired solar have not been examined here. It is expected that they would be comparable with the range represented by the heat pump appliance.

2.4 Lighting

Lighting contributes to approximately 15% of the energy use in an average Auckland house (Isaacs and Amitrano et al 2004). This equates to about 171 kg CO_2/year (average electricity fuel mix) or

513 kg CO_2 (marginal electricity fuel mix). There are several design strategies available to decrease the lighting needed for a particular area.

In any proposal to install energy-efficient lighting consider:

- the energy consumption of each lamp
- any thermal aspects
- the lighting level required (illuminance)
- smart controls and sensors.

The most effective way to reduce the energy/CO_2 intensity for lighting is simply to design all light fittings with more efficient luminaries in mind – such as fluorescent or compact fluorescent lights. A direct saving of between 75–80% is possible from this alone. According to several sources,[6] improvements in fluorescent lighting technology mean that this lighting is an acceptable substitute for incandescent lighting in nearly all applications.

In the UK, there have been suggestions (BRE 2004) to select luminaries which only accept compact fluorescent lamps (CFLs) to discourage the future reversion back to conventional filament lamps. In this case, the control gear for the lamp is contained in the fitting, so upon lamp failure only the lamp needs replacing. Although it is possible to buy separate control gear for the lamps in New Zealand, they are excessively expensive and considerably more difficult to source across. For these reasons, they are therefore not considered practical for application in carbon-neutral buildings at the time of writing.

It has become common practice in New Zealand to incorporate recessed halogen lighting in the ceiling areas of kitchens, lounges, dining rooms and bathrooms.[7] In addition to being not very effective at converting electricity to light, most often this type of lighting is not properly thermally insulated, acting as a very effective thermal bridge between the conditioned and unconditioned spaces. This can severely compromise the thermal design (Stoecklein 2005). This situation can be rectified either through:

- a change in the design so that halogen-based recessed downlights are not required, or
- the careful specification and construction of insulated lighting units.

Other lighting design strategies include:

- specifying only as much lighting as is necessary for the task and making use of spot or task lighting where appropriate
- incorporating energy-efficient controls, such as daylight sensors and proximity sensors on external lighting and timer switches on stairway lighting. External lighting can include areas such as patios, front and back entrances, pathways and inter-building transitions zones.

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[6] For example, *Energy-efficient Lighting for Houses,* (1998) Good Practice Case Study 361, Energy Saving Trust as part of the Energy-efficient Best Practice Programme in Housing series, UK and also

[7] Although LED recessed lighting options are available (for example, a 1.5W 18 cluster LED replaces a 15W halogen lamp commonly used for down-lighting), they are still considerably more expensive than the standard option. However, the costs of this durable technology (with a life expectancy of 15,000 hours +) are rapidly decreasing, so should be considered as an option.

2.5 The oven / hob

According to HEEP data, the hob and oven combined account for about 8% of the total energy load of a typical house (Camilleri 2005). The energy use between the two functions is approximately a 50/50 split. In an all-electric house, this equates to approximately 632 kWh or 284 kg of CO_2 annually.

Table 4 examines the efficiencies of different types of range tops for the carbon emitted per cooked unit (in this case 10 kWh). CO_2 emissions from electricity are based on peak times, since cooking is normally done during this time. This table needs to be read with the following qualifiers:

- gas hobs are becoming difficult to purchase since the market shift to electrically powered ovens in New Zealand
- microwave ovens are usually a complementary cooking appliance to the main cooking appliance, so should not be compared directly to other stand-alone cooking appliances
- strictly speaking microwaves, unlike all other cooking appliances listed, are chattels. However, they are included here for completeness.

The energy factor in Table 4 represents energy conversion efficiency – i.e. the ratio of energy that is effectively used to heat food to the total energy used. Note that these results are for commercial cooking situations, as a recent, complete and independent study of home cooking appliances could not be sourced. However, these results reflect other domestic-based appliance studies.

Table 4: CO_2 efficiencies of range tops[8]

Range top	Fuel type	Energy factor (%)	CO_2 emission per cooked unit (kg CO_2 per 10 kWh)
Electric induction	Electric (peak)	81	5.6
Electric resistance	Electric (peak)	74	6.1
Gas hob (pilot light)	Natural gas	19	10
Gas hob (electric ignition)	Natural gas	40	4.8
Gas hob (LPG bottled)	LPG	40	5.5

From Table 4 it can be seen that the gas hob with electric ignition and the LPG fuelled gas hob are the most carbon-efficient, with the pilot lighted gas hob being the least. However, for a more complete carbon picture, the effect on indoor heating/cooling (especially from the gas appliances), should also be examined. In all likelihood, it is probably safe to recommend any range-top appliance apart from the gas hob with pilot light option, which is significantly more carbon intensive.

[8] Source: www.aps.com/images/pdf/Cooking.pdf

Table 5: CO_2 efficiencies of ovens[8]

Ovens	Fuel type	Energy factor (%)	CO_2 emission per cooked unit (kg CO_2 per 10 kWh)
Microwave	Electric (peak)	57.5	7.8
Electric resistance	Electric (peak)	10.9	41.3
Electric, self-cleaning	Electric (peak)	10.2	44.1
Electric, self-cleaning, convection	Electric (peak)	13.4	33.6
Gas, electric ignition	Natural gas	5.8	77.5
Gas, electric ignition, self-cleaning	Natural gas	5.8	77.5
Gas hob (LPG bottled)	LPG	5.8	77.5

For carbon intensity of ovens, it can be seen from Table 5 that the microwave oven is the most carbon-efficient while the electrically-powered self-cleaning convection and the standard electric resistance ovens also being very carbon-efficient. Here, the effect of the ovens on indoor heating/cooling is likely to be less important due to the closed nature of the appliance. The utility of the comparative appliances needs to be kept in mind, however, since the microwave is generally seen as a complementary cooking device, as previously mentioned. The low carbon preference is for a microwave/electric oven combination.

2.6 Recommendations

FOR HOT WATER HEATING

It is recommended that one of the following hot water heaters are chosen to minimise lifetime operation-related CO_2 emissions based on ***non-peak*** *generated electricity (in order of least polluting first):*

1. *wet-back using either logs or wood pellets*
2. *efficient heat pumps (with a coefficient of performance of at least 2.5)*
3. *electric-assisted solar, and*
4. *gas-assisted solar.*

It is recommended that one of the following hot water heaters are chosen to minimise lifetime operation-related CO_2 emissions on ***peak*** *generated electricity (in order of least polluting first):*

1. *wet-back using either logs or wood pellets*
2. *gas-assisted solar*
3. *efficient heat pumps (with a COP of at least 2.5), and*
4. *instant electric heater.*

Where possible, install water-efficient tap-ware and fittings (such as low-flow shower roses and flow limiters) to the plumbing system.

FOR SPACE HEATING

*It is recommended that one of the following space heaters is chosen to minimise lifetime operation-related CO_2 emissions based on **non-peak** generated electricity (in order of least polluting first):*

1. *high efficiency double wood/pellet burner*
2. *standard double burner*
3. *efficient heat pumps (with a coefficient of performance (COP) of at least 2.5), and*
4. *ducted heat pump with a COP of at least 2.5.*

*It is recommended that one of the following space heaters is chosen to minimise lifetime operation-related CO_2 emissions based on **peak** generated electricity (in order of least polluting first):*

1. *high efficiency double wood/pellet burner*
2. *standard double burner*
3. *gas heated flooring*
4. *flued natural gas.*

FOR LIGHTING

There are several design issues that will lead to a significant reduction in the amount of lighting-related CO_2 emissions. They include:

1. *Specification for fluorescent or compact fluorescent in all areas, apart from perhaps those areas only used for a very short time.*
2. *Ensuring that the building's thermal envelope is not compromised due to the presence of recessed lighting.*
3. *Ensuring that only as much lighting as is necessary for the task is specified.*
4. *Incorporating energy-efficient controls, such as daylight sensors, proximity sensors and timer switches where appropriate.*

FOR COOKING APPLIANCES

It is suggested that the design incorporates one of following preferred cooking appliances:

- *for the **range top**, anything but the gas hob with pilot light should be used*
- *for the **oven**, the best combination seems the common microwave with the convection electric oven (with or without) self-cleaning capabilities.*

3. MATERIAL-RELATED CARBON

3.1 Introduction

Ultimately, carbon accounting should extend to the chosen building materials, components and assemblies as part of the complete building being examined. For brevity, the terms 'building' 'material', 'components' and 'assemblies' will be defined in this section just as 'materials'. This section reveals some of the practical issues and limitations that result from the examination of material-related carbon assessment.

Buildings are a complex mixture of many often highly processed materials, each contributing to the building's overall embodied CO_2. When examining material-related CO_2 contributions, the whole life-cycle must be considered for a fair analysis. In doing this, the material's manufacture, transportation, upkeep for fitness of purpose, and finally its disposal at the end of its life needs to be examined. Without an extensive life-cycle assessment, a true picture of the embodied CO_2 is difficult to assess. Supporting data for an assessment is often problematic to uncover. Even when comprehensive information **is** provided, it is recognised that the CO_2 emission figures can be product-generic, and vary considerably between manufacturers. Due to the limited data available for New Zealand and the lack of standardised carbon accounting system, this section will focus on board guidelines only, providing a commonsense approach for making smart CO_2-efficient design choices.

The different material life stage contributions are defined as:

- *initial* embodied CO_2 (i.e. that CO_2 released as a result of the raw material extraction and manufacturing process only)
- *transportation-related* embodied CO_2 (i.e. that CO_2 released as a result of all material-related transportation from the manufacturer to the construction site)
- *maintenance-related* embodied CO_2 (i.e. that CO_2 released as a result of the required upkeep while installed in the building for fitness of purpose only), and finally
- *disposal-related* embodied CO_2 (i.e. that CO_2 released as a result of either its reuse, recycling, conversion to energy or land-filling).

3.2 Initial

New Zealand-specific initial (i.e. cradle-to-gate) embodied CO_2 figures are available for a limited number of building materials. In all, CO_2 intensities are provided for some 34 base materials and their derivatives (Alcorn 2003), shown in Appendix C. Individual material's initial CO_2 emission intensities are provided in grams of CO_2/kg of material or grams of CO_2/m^3 of material.

Honey and Buchanan (1992) carried out some preliminary work in the area of comparing the initial CO_2 intensity of various building typologies. Included in the examination were three variations on a standardised house.[9] The three virtual constructions were – the 'typical' house, a 'low carbon' house and a 'high carbon' house – each carefully constructed with representative materials. The main construction differences for each of the three house types (by element) are shown in Table 6.

Table 6: Comparative elements for carbon (dioxide) intensity of a standard house

[9] All houses were based on a BIAC house rescaled to better represent an existing house.

Construction type	Roof construction	Wall construction	Floor construction	Window framing
High carbon	Corrugated steel	Brick veneer with steel framing	Concrete floor	Aluminium
Typical	Corrugated steel	Concrete block with timber framing	Concrete floor	Aluminium
Low carbon	Concrete tile	Timber frame	Timber floor	Timber

It was found that houses constructed with 'typical' materials had an embodied CO_2 value of 46[10] tonnes of CO_2 (or 12.5 tonnes of carbon). This compares to having only 68% of the carbon emissions of the high carbon house and 410% of the carbon emissions of the low carbon house.[11] Converting the 'typical' figures into a more currently representative 200 m^2 house, this equates to approximately 36,700 kg CO_2 being emitted due to the construction materials alone. Assuming that the house lasts for 75 years (which is considered to be the optimum age for full rehabilitation to ensure best resource use (Johnston 1997)), this equates to a CO_2 intensity of about 485 kg per year. However, this initial embodied CO_2 figure provides only part of the picture – since the upkeep contributions need to be factored into the equation. This will be explored in more detail in later in the report (Section 3.4 Maintenance).

What can be said with certainty is that for a given palette of materials, the larger the house, the larger the initial embodied CO_2 and the larger the ongoing (i.e. maintenance and durability-related) CO_2 emissions. The effective use of space is a simple concept with important ramifications which needs to be reinforced. Other simple design concepts that will assist the best use of material resources include:

- ensuring that rooms are kept to comfortable but modest sizes
- the good utilisation of each space and the use of multi-use spaces where possible
- not designing in dedicated transition areas, such as hallways, if possible
- simplicity in form and lack of clutter
- careful detailing.

Some excellent examples of the creative use of effective small spaces can be found in a variety of books published today e.g. Brown (2005) and Truelove (2004). These should be used to extend the simplified approaches set out in the associated *Designing Homes for Climate Change* (Jaques 2006).

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10 This is based on a doubling of the BIAC 94 m^2 house, to better represent the typical new house of 114 m^2.

11 These figures need to be interpreted with a degree of caution mainly due to the CO_2 figures being largely derived from now very old (early '70's input output tables (Baird and Chan, 1983). In Alcorn's (2003) update of these figures, it was shown that large differences in intensities between the old and the new were now common, with many of the figures being substantially reduced as a result of changes to industry practices.

3.3 Transportation

It is generally considered that the *transportation-related* CO_2 contribution for most materials is low, compared to the CO_2 contributions from other stages of its life-cycle stages (Alcorn 2005). The exception to this is for dense items which have very little processing energy as part of their manufacture (*Environmental Building News* 1997). Examples of these are stone and sand. However, since these materials are by far the minority used in residential construction, their CO_2 emissions will be neglected for this report.

3.4 Maintenance

Often neglected in building-related CO_2 accounting is the carbon invested as part of a building's periodic maintenance, ensuring that the provided space is fit for its intended purpose. This is distinct from the carbon invested in a building as a result of shifts in fashion and other non-maintenance reasons.

Maintenance-related carbon requirements can be considerable, as often heavily processed materials are used e.g. paints, flooring coverings and metals. 'Typical' replacement and maintenance figures are given in Table 7 below, representing a 200 m2 light timber-framed house. Once again, the size and material selection of the building is based on that typically built with a concrete floor, long-run steel roofing and aluminium window framing. The information for Table 7 was taken from a variety of sources – Honey and Buchanan (1992), Alcorn, (1996) and Mithraratne (2001). All the CO_2 values are indicative as there are no accepted guidelines or standards dictating such issues as 'useful life' and replacement cycles are very subjective. A pro-rata approach is used for the estimation so that the resulting figures can be applied to any anticipated building lifetime. Note that only non-chattel appliances are accounted for.

Table 7: Typical maintenance-related CO_2 emissions

Maintenance or replacement issue addressed	Period (years)	kg CO_2 released	CO_2 percentage
Repaint roof (two coats)	7.5	3,021	7.5
Repaint interior walls	15	812	2.0
Repaint exterior walls (two coats)	10	1,525	3.8
Replace wallpaper	15	1,376	3.4
Replace polyester carpet	15	3,630	9.0
Replace PVC flooring	15	15,624	38.8
Replace stainless steel shower	30	152	0.4
Replace taps and valves	30	3	0.0
Replace two sink units	30	190	0.5
Replace stove	20	167	0.4
Replace hot water cylinder	15	162	0.4
Replace spouting	50	0	0.0
Replace long-run roofing	50	0	0.0
Replace aluminium window frames	30	7,650	19.0
Replace window glass	30	3,795	9.4
Replace polyester curtains	15	2,131	5.3
		TOTAL	**100**

It should be noted that recycling the higher embodied carbon items has the potential to significantly reduce the overall CO_2 contributions. Notable in this case are the aluminium window frames, where 90% of the energy requirements are able to be saved if recycled. However, this option is not usually available for the other carbon intensive items.

As can be seen, in maintaining a 'typical' house, around **40 tonnes of CO_2 over a 50 year period** – which equates to **just over 800 kg of CO_2 annually** – are emitted. Categorising the building materials by type, the percentage CO_2 contributions are: Finishing (65%), Joinery (28%), Plumbing (1%) and Other (6%).

Given the carbon significance of surface finishes, designers should use:

- materials and systems that are long lasting, but not much longer that the expected lifetime of the building if the intent is not to reuse the item
- finishing systems which have similar durability to conventional systems but have lower embodied CO_2 emissions. For example, when using paints:[12]
  - the preference is for oil-based emulsion and wood/vegetable 'natural' paints or casein (protein) paints (provided durability equivalency is met) or clay paints
  - a better than the conventional (i.e. alkyd/acrylic) choice is for mineral/stone paints
- durable surfaces which require no applied surface finishes (such as stone, glass and aluminium).

Note on combining initial and maintenance-related CO_2 emissions
Recently, BRANZ has made an online tool available[13] which accounts for the initial and maintenance-related CO_2 emissions of building materials. The calculation tool specifically looks at 16 common lightweight framing cladding materials applicable to dwellings. Heavy wall systems are omitted due to their composite nature and their differing thermal properties which would require additional thermal allocation as part of the CO_2 calculation.

The initial embodied figures are based on the work of Alcorn (2003). In terms of maintenance, only fitness for purpose is considered and rather than basing maintenance regimes on best practice a more 'common practice' scheme was used to better reflect reality. Thus the painting cycles, for example, are longer than optimally recommended from a durability point of view.

The BRANZ calculation tool enables the environmental impacts to be combined to give an overall 'score' for each of 16 common lightweight claddings. It gives results by lifetime embodied energy, lifetime embodied CO_2, lifetime costs and recyclability. The user is able to dictate weighting for each of these four categories according to their personal preference. Table 8 below shows the top performing lightweight claddings along with their recyclability/reuse potential. The score ranges between 0 and 100 – the higher the score the poorer performing.

[12] From GreenSpec UK directory, at www.greenspec.co.uk
[13] www.branz.co.nz/main.php?page=Lifecycle_wallclad

Table 8: CO_2 comparison of better performing lightweight framing cladding systems

Lightweight cladding type	Life-cycle CO_2 score (lower is better) with recycling discounted
Timber weatherboard, radiata, H3, 150 mm	10
Natural stone, Hinuera, veneer	41
Ply sheet, 12 mm H3, band-sawn, battens, no coat	22
Timber weatherboard, cedar, no coat, 150 mm	0
Fibre-cement sheet 7.5 mm textured coat	19
Stucco	10
EIFS, 60 mm EPS, mesh, plaster, paint finish	25

From Table 8, it can be seen that (assuming no materials are recycled) the timber-based cladding systems and the stucco finish fare very low carbon options. Due to the incompleteness of this tool (e.g. it does not include heavyweight cladding systems), its usefulness is limited and will therefore not be included within the recommendations. However, it is included here for completeness.

3.5 Disposal

Only a cursory overview of the possible material and component end-of-life (i.e. disposal-related) scenarios will be examined in this report. This is due to the:

- paucity of comprehensive, verifiable and internationally-accepted practices in end-of-life carbon accounting
- complexity of the area (e.g. the variety of end-of-life scenarios possible for many materials)
- difficulty in predicting what recycling options will be available at the end of a particular material's lifetime, 15, 50 or 100+ years away
- likelihood in terms of relative carbon significance compared to the initial and maintenance-related stages.

The disposal options for building materials and components can be grouped into the following categories:

- reuse (i.e. the use of the material in a condition unaltered from its original condition)
- recycling (i.e. the reprocessing of a material – whether into a product of the same or lower value)
- burning for energy use, and
- land-filling/clean-filling.

For disposal-related CO_2 emissions for building materials it can be reasonably stated that, everything being equal, the reuse of the material in its unaltered form is the 'disposal' option which will incur the least CO_2 cost. The likelihood of a material being reused at the end of its initial life can be greatly enhanced by careful construction in the first place. This is called ‘designing for deconstruction’. Essentially, this is the science of engineering for smart disassembly at the design stage, ensuring the maximum use of a resource. Although its principles have been commonly discussed among resource-efficient designers for some time, there has been precious little technical documentation (such as that contained within working drawings) supporting the ideas. This has changed recently (if only for the commercial building scene) with the addition of the Scottish Guide (Morgan and Stevenson 2005)

Determining the CO_2 characteristics (and therefore the most favourable responses) for the other three disposal options is not a simple task, as it is dependent on such variables as the:

- availability and proximity of local recycling markets
- availability, proximity and cost of local land-fill and clean-fill options
- amount of that product generated on a particular building site, and therefore the likelihood of it being disposed of in bulk
- inherent value of the product
- combustion characteristics of the product.

These variables will be specific for each demolition or deconstruction site. It is well known that for some particularly energy/CO_2-intensive materials (such as aluminium and copper), the best option in terms of energy/CO_2 emissions is to recycle them even if the transportation distances required are significant. However, for most materials which have a lower embodied energy/CO_2 intensity the best option is less clear and would need to be assessed on a case-by-case basis. As yet, there are no practical tools available for this that can be used on a building site. However, a significant amount of work comparing the environmental cost of various disposal options has been carried out in New Zealand as part of an attempt by environmental consultants Woodward-Clyde to provide New Zealand with a Life-cycle-based Waste Management Tool in the late 1990s.[14] This culminated in a decision support program targeted specifically at the local authorities that looked at a wide range of environmental issues, rather than just CO_2. Unfortunately this program is applicable to building sites targeting CO_2 emissions alone, due to its broader (environmental) intent.

3.6 Recommendations

INITIAL

The practical design recommendation about the initial embodied CO_2 for materials is that it must be viewed in association with ongoing material maintenance, overall product durability and the potential for recycling at the end of its initial life. As a result, it would be unwise to recommend one particular material over another based on the material’s initial embodied CO_2 emissions alone. However, other design strategies can be employed to ensure the best/efficient use of materials, including:

- *ensuring that rooms are kept to comfortable (minimum) sizes*
- *the good utilisation of each space, and the use of multi-use spaces, where possible*
- *not designing in dedicated transition areas, such as hallways, if practical*

[14] This project was partially funded by the Ministry for the Environment under their Sustainable Management Fund (referenced as Project # 4137).

- *simplicity in form and lack of clutter*
- *the selection of more timeless designs, incorporating neutral colours and not following trends and fashion-based architecture.*

If employed effectively, these design strategies will minimise the demand for materials in the first place.

TRANSPORTATION

The practical design recommendation about transportation-related CO_2 contributions associated with building materials is to disregard it, as a general rule, given its lack of significance.

MAINTENANCE

The practical design recommendation about maintenance embodied CO_2 for building materials is to use:

- *materials and systems which have long life surface finishes, but not much longer than the expected lifetime of the building if the intent is not to reuse the item*
- *finishing systems which have lower embodied CO_2 where possible, while not compromising on other performance aspects.*

DISPOSAL

The practical design recommendations about carbon-efficient building material/component disposal is limited to:

- *applying deconstruction design principles and technical details, if possible, to assist material's reuse in another building/application*
- *ensuring that the higher embodied energy/CO_2 intensive materials are reused, or if not possible/practical, recycled.*

Given the complexity of the disposal scenarios for building materials and the limitations in currently available information, these are only two design recommendations that can be applied nationally.

4. TRANSPORTATION-RELATED CARBON

4.1 Introduction

The issue of household-related transportation for employment, food sourcing, social engagements, recreation, etc, could easily be considered outside the scope of this background report. However, it was decided to include it in this report as:

- a dwelling's geographical placement in relation to its surrounding amenities has large consequences for the overall household-related carbon intensity and is intrinsic to it
- transportation-related CO_2 emissions are often overlooked in many supposedly high performance eco-homes which would otherwise have a low carbon footprint.

The Ministry for the Environment[15] estimates that transportation contributes approximately 44% of New Zealand's carbon emissions. They suggest adopting more sustainable transport practices to reduce greenhouse gases. These include:

- the use of public transport
- walking or cycling
- improving car use efficiency – through car pooling, using fuel-efficient vehicles, driving more efficiently etc
- using cleaner fuels and technologies
- using telecommunications to reduce or replace physical travel, such as tele-working
- planning the layout of cities to bring people and their needs closer together and to make cities more vibrant and walkable.

Several of these suggestions touch upon, either directly or indirectly, the obvious and easy benefits of siting a house close to amenities.

To get an understanding of the magnitude of typical household transportation-related CO_2 emissions, indicative calculations have been performed. No verifiable private car travel distance figures for the average New Zealand household could be gained by the author. However, typical private car travel estimations range between 10,000–20,000 km annually. Taking an upper figure of 17,000 km per year travelled by the average sized petrol car of about 1.9 litres, which has CO_2 emissions from around 2.7 kg/l and efficiency of 6.3 l/100 km, this results in an annual CO_2 emission per household of 2.88 tonnes of CO_2. This surpasses the yearly upkeep (i.e. maintenance) CO_2 emissions, which is just over 800 kg of CO_2 annually, by comparison.

The CO_2 implications of using other modes of transportation are shown in Table 9, where typical transportation CO_2 emissions per km travelled are given (adapted from BRANZ's *Being a Climate Friendly Kiwi* (2002). These estimates are based on expected loadings for public transport. The CO_2 benefits of walking, cycling and the use of public transport can clearly be seen.

[15] www.mfe.govt.nz/issues/transport/sustainable/ accessed 17 Jan 2006.

Table 9: CO_2 emissions by mode of transport

Transportation mode	Emissions (CO_2 emissions kg/km travelled)
Petrol car (average size)	0.21
Diesel car (average size)	0.15
Train – diesel	0.09
Train – electric	0.17
Bus	0.02
Ferry	0.21
Cycling/walking	Negligible

Naturally, the efficient use of transportation generally has implications for many other environmental issues as well, such as conserving non-renewable resources, relieving congestion, air pollution avoidance, reduction in noise, safety etc. However, these implications are outside the scope of this document.

So what building-related carbon guidance can be given in terms of transportation? A recent document (Forest Research/BRANZ et al 2001) on smart growth examined the proximity to amenities for existing and future development and infrastructure. It was suggested that, if possible, residential buildings should be less than 500 m to employment, schools/shops, day care and recreation, but up to 800 m was deemed as 'acceptable'. In terms of distance to a transport centre/public transportation service, it was suggested that dwellings be less than 400 m, with up to 800 m being considered as 'acceptable'. These figures may seem very optimistic for many urban situations, but they should be aspired to as part of a comprehensive low carbon design package. These figures also relate well to the BRANZ *Green Home Scheme*, an environmental assessment tool for new house designs. The assessment scheme recognises and rewards dwellings located within 350 m and 500 m (measured as the crow flies) to public transport or at least three key amenities.

The benefits of siting houses in close proximity to transportation routes/amenities does assume that the household occupants have the ability and motivation to actually make use of lower emitting transportation options. Everything being equal, people will make use of services and facilities which are easier to access.

4.2 Recommendations

The flowing transport-related design recommendation can be made. Ensure that the residential site selected is close (i.e. within a walking distance of say 500 m) to key amenities, such as employment, schools/shops, financial and recreation facilities. Alternatively, choose a site which is within walking distance (i.e. 500 m) of a public transportation service.

5. SUMMARY OF CARBON-CONSTRAINED DWELLING

Initial and ongoing carbon-related implications of key building-related design issues typically encountered as part of the design process for a new dwelling were examined. Issues included: the building's thermal performance, fenestration aspects, the choice of the major appliances (including lighting systems) and the selection of the construction materials. In addition, due to the close relationship between the siting of a dwelling and its transport needs, the issue of house siting was also examined.

The resulting recommendations are patchy, mainly due to the complexity of the interactions between the building and the occupants and the lack of comparative data on the subject. However, some generic design advice on low carbon dwelling is still possible which is applicable to most houses at the design stage nationally. It should be noted that these recommendations do not necessarily take into account other issues, such as the ease of use of the suggested appliance, the availability of the suggested fuel source, ongoing maintenance concerns etc. However, in terms of low carbon living, designs should consider the following concepts:

- **Good passive solar design is essential**. This maximises the opportunity to use a renewable energy source to provide comfortable all-year living. Optimally, it means that no purchased energy is needed for heating/cooling for many parts of New Zealand and only occasional heating requirements for the remaining parts.
- The most carbon-efficient **hot water heaters** commonly available are: high-efficiency enclosed wood-burners with wet-back systems using wood logs or wood pellets, gas-assisted solar systems, efficient heat pumps or instant electric heaters.
- The most carbon-efficient **space heaters** commonly available are: wood pellet burners, central heating wood pellet burners, flued gas heaters (convection), gas-fired central heating and flued gas heaters (with a flame effect).
- Specify only as much **artificial lighting** as required, make good use of day lighting and use (compact) fluorescent lamps for all situations.
- When deciding upon **cooking appliances**, a gas hob or electric induction range top are the most carbon-efficient, with the microwave and conventional electric resistance oven the most carbon-efficient ovens.
- To reduce a building's **material-related** carbon emissions, the following design strategies should be used:
  - *ensure that rooms are kept to comfortable (minimum) sizes*
  - *ensure that each space is utilised effectively*
  - *not designing in dedicated transition areas, such as hallways, if practical and possible*
  - *aim for simplicity in form and lack of clutter*
  - *specify durable surfaces that require no surface finishes* or *materials and systems which have long life surface finishes, but not much longer than the expected lifetime of the building if the intent is not to reuse the item*
  - *choose finishing systems which have lower embodied CO_2 (energy) where possible, while not compromising on other performance aspects*
  - *apply deconstruction design principles and technical details, if possible, to assist material's reuse in another building/application*

- *ensure that the higher embodied energy/CO_2 intensive materials are reused, or if not possible/practical, recycle if at all possible/practical.*

- For site selection for minimising transport-related carbon, ensure that the site is within a walking distance (say 500 m) of key amenities such as employment, schools/shops, financial, and recreation facilities. Alternatively, choose a site which is within walking distance of public transportation.

In addition, Greenpeace recommends using an electricity supplier who provides the bulk of their electricity through renewable sources such as hydropower and wind etc (e.g. Meridian Energy). This will ensure that the electricity component used within a household has very little carbon content.

SECTION B: TOWARDS CLIMATE-ADAPTED DWELLING

The anticipated impacts of climate change for New Zealand are increased rainfall amounts and intensity over most of New Zealand, increased extreme summer temperatures, increases in flooding and rising sea levels. Changes in tropical cyclones, the El Nino and La Nina weather patterns, wind, sunshine and cloudiness occur but the drivers for these changes are not yet fully understood (Camilleri 2000).

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

High temperatures inside houses will affect the comfort of occupants, especially those groups deemed to be vulnerable to extremes in temperature (the elderly, infirm and young children) and especially when day-time work performance or night-time sleeping is affected. When high temperatures are coupled with high humidity (predicted for cities such as Auckland), the likelihood of mould proliferation, strongly linked to health problems, is also increased (Sanders and Phillipson 2003). Positive impacts include higher night-time winter temperatures and decreased winter energy consumption.

The action of wind on buildings causes dynamic structural loading by pressure forces. Structural failure can range from removal of individual tiles or iron sheeting through to uplifting of entire roofs or walls. High wind speeds also have implications for the wind environment surrounding buildings, such as comfort and/or safety issues for pedestrians (Sanders and Phillipson 2003).

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

The anticipated changes of rainfall, wind and flooding, and the resulting implications and how their effects can be mitigated in new house designs will be overviewed. The issue of overheating has been omitted, as it has already been addressed in Section A.

6. RAINFALL IMPLICATIONS

6.1 Introduction

Rainfall changes may take on a number of forms, including that of more intense rainfall, increased driving rain and more extreme rainfall events. However, the changes in rainfall are geographic. Mean and extreme rainfall is projected to increase in the west and south of New Zealand, whereas in the north and east mean rainfall will either have no change or decrease. Projected annual mean percentage changes for precipitation for 2100 are shown in Table 10.

Table 10: Indicative regional precipitation resulting from climate change (modified from Ministry of Environment 2001)

Region	Precipitation
Northland, Auckland	-10% to 0%
Western North Island from Waikato to Wellington	0% to +20%
Eastern North Island from Bay of Plenty to Wairarapa	-20% to 0%
Nelson, Marlborough to coastal Canterbury and Otago	-20% to +5%
West Coast and Canterbury foothills	+5% to + 25%
Southland and inland Otago	0% to +30%

Specifically, Taranaki, Manawatu-Wanganui, West Coast, Otago and Southland are expected to have increased rainfall in the 2080s. Hawkes Bay and Gisborne are expected to have decreased rainfall in the 2080s (Ministry for the Environment 2004). Canterbury is expected to have smaller changes than the rest of the country. However, rainfall is expected to increase in the Canterbury foothills (Christchurch City Council 2002).

Heavy rainfalls are likely to become more frequent in New Zealand; however their exact size is still uncertain. Whetton et al (1996) have predicted that the return period of heavy rainfall events will be reduced. This essentially means that the return period of heavy rainfall events may halve by 2030 and may reduce by four times by 2070 (Ministry for the Environment 2004).

6.2 Impacts

The impacts on buildings from increased rainfall include damage to building facades, internal structural damage, leaky buildings, rain penetration around openings and greater pressure on drainage systems (BRE 2005).

6.3 Design implications

Design principles should be employed to achieve good moisture management: deflection, drainage, drying and durability. The building elements that need to be considered are:

- roof edges
- open decks
- walls and joinery
- retaining walls

- floors
- balconies
- wall/roof junctions
- roofs.

The impacts of driving rain can be reduced by improving the weathertightness of the dwelling using the following advice:

- continuous unbroken areas of roofing offer less risk of leaking than roofs with different pitches and angles
- locate rainwater collection systems on the outside of the building to avoid internal box and valley gutters overflowing into the building
- install generous overflow areas and rainwater heads at downpipes if internal gutters need to be installed
- steeper pitched roofs shed water quicker, thus reducing leakage under roofing laps and flashing
- design low profile building without high wall areas facing the prevailing winds in order to reduce the amount of wind-driven rainwater collecting on the wall
- generous eaves and overhangs (600 mm+) help protect the wall from rainwater wetting
- use monolithic or sheet claddings – more likely to resist leaking in extreme winds
- use rainwater heads to feed water into downpipes – improves downpipe efficiency
- leave externally located downpipes unsealed at drain entry points – avoids spoutings and gutters overflowing if stormwater drains become blocked
- limit the number of roof penetrations to reduce the risk of leaks occurring
- install head caps and head flashings on all openings
- provide rigid sheet wind barriers behind all claddings and seal them around wall openings and penetrations
- install drainage cavities behind claddings.

7. WIND CHANGES (INCLUDING CYCLONES)

7.1 Introduction

Wind-related scenarios have only been briefly investigated and it is unknown what the impacts of a changing climate will be on the frequency, duration and intensity of wind (Camilleri 2001). However, the Ministry of Environment have projected that there may be an intensification of prevailing westerly winds in the southern and mid-to-high latitudes. For the 2080s, the annual mean westerly wind component across New Zealand may increase by 60%. The highest wind speed could increase by 3% by 2080, occurring once a year. Regional variability of winds across New Zealand is still uncertain (Ministry for the Environment 2004).

Tropical cyclonic activity due to climate change is not fully understood. However, due to the mass destruction that could be caused by cyclones, it would be a more prudent measure to adapt against them now rather than face the consequences later.

Increased cyclonic events would bring with them increased driving rainfall and extreme winds, particularly in Northland. Stronger winds may be experienced on land in the west coast, with initial wind, storm surges and waves on the east coast (Camilleri 2000).

7.2 Impacts

High winds could cause structural damage – removal of roofing materials, damage to windows or guttering from direct wind or flying debris and increased weathering of a building. The wind environment around buildings may also be affected, in turn affecting the comfort and safety of pedestrians (Sanders and Phillipson 2003).

7.3 Design implications

There is little evidence to date that increased winds will occur due to climate change in the next 100 years. However, the devastation caused by cyclones is so massive that it is more prudent to adapt buildings in potential high-risk areas now. Areas most likely to be at risk are Northland and Auckland. It would be prudent to increase the structural strength to the next higher NZBC wind zone to limit any potential damage. Alternatively, designing buildings that are more aerodynamically efficient will also decrease wind loads on the structure. How to test for this, however, is unknown.

Roof areas are the most likely part of the house to succumb under attack from high winds. The following adaptations may reduce the risk of roof damage:

- construct steeper pitched roofs – above 17° built at right angles to the prevailing wind means that uplift pressures are only experienced on down-wind sides
- install extra fixings at roof edges – this will minimise uplift pressures which occur along eaves, ridges and barges
- install extra hold-down straps on purlins over external wall lines
- construct mansard roofs.

8. FLOODING

8.1 Introduction

Flooding of both coastal and inland areas is predicted to increase with increased rainfall and cyclones, while flood return periods decrease. Flooding could become four times more likely across New Zealand. The areas predicted to be most liable to flooding are the west coast of New Zealand, rivers with catchments near the main divide in the South Island and the central plateau of the North Island (Ministry for the Environment 2001). However, flooding will not be confined to these areas. Drought areas such as eastern North and South Island may also be affected due to extreme heavy rainfall (Ministry for the Environment 2001). Urban drainage systems which cannot cope with increased and extreme rainfall will become blocked and flood surrounding areas (Camilleri 2000). The acceptable level of risk for flooding according to the NZBC is a 2% annual risk of over the floor flooding.

8.2 Impacts

Drainage systems may be unable to cope with increased run-off due to heavy and extreme precipitation. Overflow charges may result in surface flooding, causing sewage intrusion and furthermore associated impacts of contamination and health issues. As typical houses are designed to connect to the mains system, this is an area for urban drainage engineers to consider.

Results of flood activities on buildings include water damage (e.g. internal plasterwork, underfloor and wall insulation), drain damage (e.g. to guttering), damage to infrastructure and communications, corrosiveness of sea water (e.g. masonry damage) and run-off from agricultural land (e.g. fertilisers and soil minerals). Dwellings could possibly be completely destroyed in flood-prone coastal or inland areas (O’Connell and Hargreaves 2004).

8.3 Design implications

The best suggestion is not to build in a vulnerable site. The most important method in reducing flood related issues is to avoid siting buildings on river flood plains and low-lying coastal areas. (O’Connell and Hargreaves 2004 – adapted from Camilleri 2001). It should be noted that as the climate and land mass changes, there may be no warning of future buildings in flood-prone areas due to earthquakes, erosion, landslips etc and the continued desire by people to live “by the water”.

There are a number of measures to minimise the risk and severity of flooding. The sequence should be:

1. Researching the risk of flooding in any given site in any given region (i.e. look at the flooding return period). This information can be obtained from local councils and environment agencies.
2. At the design stage, exceed the minimum floor level clearance requirements in order to reduce the risk of flood damage.
3. Design with flooding in mind for the lowest levels of the house, using the wet-proofing and dry-proofing methods (see below) and installing essential, vulnerable equipment as high as possible.
4. Use water-resistant materials (see Table 11).

Table 11: Suitability of various building materials for water tolerance

Material	WATER-RESISTANT	NON-WATER-RESISTANT
Insulation	Closed cell foam (extruded polystyrene or polyurethane)	Fibreglass, mineral wool, wool, cellulose, foil
Floors	Concrete (bare or coated) Floorboard, durable or treated timber	Particleboard, MDF, plywood Ceramic tile
Walls	Fibre-cement Concrete block Durable or treated timber PVC Brick (glazed or faced)	Particleboard, plywood
Interior	Concrete block Fibre-cement Durable or treated timber	Plasterboard Plywood Hardboard Softwood Carpet or vinyl Particleboard

Building concrete slab floors rather than a low suspended floor may be advantageous as they can provide an effective seal against water which may rise up through the floor. They also incur less damage if flooded and are faster and less expensive to restore after a flood event. Concrete floors with damp-proof membranes are the most flood-resistant floor type.

The most effective concrete floors are those with:

- effective connections between the damp-proof course in the walls – these should be installed so as to minimise ingress floodwater at the floor/wall joint
- rigid boards with a low water absorption should be used as insulation for solid concrete floors
- membranes that are between the surface screed and the concrete slab as these help to dry out quicker after flooding.

Polystyrene raft slab floors can also give large ground clearances. Alternatively, consider multi-storey construction and pole buildings.

FLOOD-PROOFING

There are two methods of flood-proofing – dry-proofing or wet flood-proofing. Dry-proofing aims to keep water out of the building, whereas wet-proofing is those measures aimed at improving the ability of the building to withstand a flooding event (OPDM 2003).

Dry-proofing methods:

- install moveable flood protection barriers for openings (doorways, low level windows)
- installation of return values on sewers to prevent backflow.

In reference to installing moveable flood protection barriers for openings, these include temporary flood barriers so they can be put up if a flood warning is issued or before flood waters reach the house – airbrick covers, flexible skirting systems, frames around doors that provide a watertight seal. However, it must be noted that these mitigation methods are more appropriate if the house is located in a floodplain, where flooding is known to occur. The first step in this case should be not to build in a flood area.

Wet-proofing methods:

- use water-resistant materials during construction for insulation, floors, walls and the interior (see Table 11)
- install building services (wiring, meter boards etc) above possible flood levels or as high as practical
- use plastic cable conduits to plaster cables directly into the wall
- ensure plastic-coated electrical wires are waterproof.

For external concrete walls, water-resistant paints and coatings can be used to help prevent floodwater soaking into the external face of the wall, allowing it to dry out quicker in the case of flooding. Coatings should be applied to 500 mm above the maximum expected level of flooding. Plaster applied to the internal face of concrete walls should consist of flood-resistant materials, such as internal water-resistant render and lime-based plaster finish, ceramic tiles and hydraulic lime coatings. With ceramic tiles, it is important to use water-resistant grouting (OPDM 2003).

Solid doors and frames are less susceptible to flood damage. Using oil-based or waterproof stain/paint can minimise distortion. Lime-based paints or emulsions allow walls to dry out quicker after flooding.

In summary, do not build in a flood-prone area i.e. siting buildings on river flood plains and low lying coastal areas. Territorial Authorities should have information and databases which readily identify such problem areas (O'Connell and Hargreaves 2004). However, for areas of new development, other additional indicators should be observed such as whether the house is:

- near a property that has flooded
- in a natural drainage area.

9. SUMMARY OF CLIMATE-ADAPTED DWELLING

It is anticipated that climate change will result in more intense rainfall events, a possible intensification of the prevailing westerly winds in select locations, and increased flooding in both coastal and inland areas. The implications for these changes on houses and possible design and build solutions for them have been overviewed. The recommendations are summarised below:

To mitigate the effects of more **intense rainfall**:

Design principles should be employed to achieve good moisture management i.e. deflection, drainage, drying and durability. The building elements that need to be considered are roof edges, open decks, walls and joinery, retaining walls, floors, balconies, wall/roof junctions and roofs.

The impacts of driving rain can be reduced by improving the building weathertightness:

- using continuous unbroken areas of roofing with a simple line
- avoiding internal box and valley gutters
- installing generous overflow areas and rainwater heads at downpipes if internal gutters need to be installed
- using steeper pitched roofs
- designing low wind profile buildings
- having generous eaves and overhangs
- using monolithic or sheet claddings
- using rainwater heads to feed water into downpipes
- leaving externally located downpipes unsealed at drain entry points
- limiting the number of roof penetrations to reduce the risk of leaks occurring
- installing head caps and head flashings on all openings
- install drainage cavities behind claddings.

To mitigate the effects of more **intense winds** (only for the Auckland/Northland areas):

It is suggested to increase the structural strength to the next higher NZBC wind zone to limit any potential damage. Roof areas are the most likely part of the house to succumb under attack from high winds, therefore:

- construct pitched roofs above 17°, built at right angles to the prevailing wind, so that uplift pressures are only experienced on down-wind sides
- install extra fixings at roof edges to minimise uplift pressures
- install extra hold-down straps on purlins over external wall lines
- construct mansard roofs.

To mitigate the effects of more **flooding**:

- DO NOT BUILD IN A VUNERABLE SITE
- exceed the minimum floor levels
- consider multi-storey construction
- use water-resistant construction materials
- install essential, vulnerable equipment as high as possible.

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APPENDIX A: USEFULNESS OF SOLAR SHADING

Table 12: Solar control effectiveness of shading systems[16]

Shading System	Best for	Relative solar shading (%)
Clear double glazing, no shading		0
Overhang	N	45
Light shelf	N	49
External louver: shut	H	96
External louver: open	H	74
Tinted glazing	NEWH	29
Heat mirror glazing	NEWH	34
Window film	SEWH	49
Reduce window area	Any	50
Mid-pane venetian: shut	NSEW	57
Mid-pane venetian: open	NSEW	57
Fixed mid-pane louvres	H	63
Curtains	Any	50
Venetian blind: shut	Any	43
Venetian blind: open		43
Roller blind	Any	57
Reflective roller blind	Any	66

Key to table:

N = North
S = South
E = East
W = West
H = Horizontal

[16] Adapted for the southern hemisphere from Littlefair P.J. (1999), *Solar Shading of Buildings*, BR364, Construction Research Communications Ltd, London, UK, via the design guidance document by Orme and Palmer (2003).

APPENDIX B: EMISSIONS BY FUEL TYPE

With emissions factors for fuel types, there has yet to be a consensus reached for two types – electricity and fuel wood. This makes the carbon calculation for these fuel types problematic. However, for the electricity figure, the at-the-margin figure has been used by many in the building (Camilleri 2001, O'Connell et al 2004 etc) and non-building related fields, as it is seen to be more reflective of future conditions.

It can be argued that anyone seriously considering a carbon-neutral house will have a significant portion of their energy generated through renewable means. In this case, it would not be fair to assign at-the-margin emissions to the occupant, and an average electricity emission figure should be used. This would better reflect the zero carbon home-owner who would be less reliant on peak electricity demand. For this report, both average figures of 0.15 kg CO_2 per kWh electricity delivered and peak figures are used.

In terms of the fuel wood figure, the figure used (0.01kg CO_2/kwh) is based on recent (Nebel 2005) life-cycle inventory work carried out by Scion using the Gabi life cycle assessment tool. It includes the establishment, pruning, thinning (carbon sequestration) harvesting, transportation, cutting up and burning of the wood using commercially grown crops. It is unknown how representative this is.

It should be remembered that each fuel has other (non-CO_2) pollutants, and there is no such thing as the perfect fuel. Indeed, assessing a fuel type just on its carbon (dioxide) emissions can be misleading and disingenuous, due to the factors which are not accounted for.

Taking fuel wood as an example (which is probably one of the more difficult fuels to account for in terms of its CO_2 emissions), the simplified life cycle assessment above doesn't take into account:

- combustion issues, such as the likely dampness of the wood, the likely selected burn rate (and therefore combustion efficiency) etc
- any aerobic decomposing resulting from prunings during the silviculture
- non-CO_2 greenhouse gases during its lifetime
- other environmentally damaging impacts – associated with ozone depletion, resource depletion, acidification, eutrophication, ecotoxicity, human toxicity etc.

Several energy experts were asked for their assessment on the embodied (net) CO_2 of New Zealand grown fuel wood, but there was little agreement on what it should be.[17] This is, in part, indicative of the many assumptions that it is necessary to establish a representative/appropriate figure for the New Zealand case. For this report, it has been assumed that the wood is grown commercially and in a sustainable fashion within a plantation. This figure was then doubled, to account for the timber which is not grown and logged so efficiently.

As stated by Vale (2004):

- it is correct to use a CO_2 multiplier for wood (thus wood should not be considered to be carbon-neutral)
- if (fuel) wood is counted as an environmentally neutral (or beneficial) fuel there is no incentive to save it

[17] A concerted effort is being made to rationalise and form a set of nationally agreed-upon CO_2 coefficients for the various fuel sources, as part of the life-cycle assessment initiative.

- nearly all wood burning produces a wide variety of pollutants other than CO_2 which can act as a reasonable proxy for these other pollutants.

The importance of fuel wood should not be under-estimated as a primary form of space heating. Just over half the houses statistically sampled as part of a recent nationwide house energy study had a wood burner installed. As stated in the HEEP Year 9 report (2005) "*solid fuel burners would appear to be at least as important as electricity for space heating*"(available as a download through www.branz.co.nz).

Table 13 presents the CO_2 emission intensities for the various fuel types applied to this background report.

Table 13: CO_2 emission intensities for various fuel types

Fuel type	kg CO_2/kWh delivered	kg CO_2/MJ delivered
Electricity (off-peak)	0.15	540
Gas (mains)	0.19	648
Gas (LPG bottled)	0.22	792
Coal	0.6	1296
Diesel	0.25	900
Fuel wood	0.01	36

s

APPENDIX C: EMBODIED ENERGY AND CO_2 FIGURES FOR COMMON NZ BUILDING MATERIALS

Note that Table 14 needs to be interpreted with caution – as durability of the material, its future recyclability at the end of its initial life, fitness for purpose (i.e. function), accessibility for replacement, likelihood of obsolescence, etc, all need to be considered. The ability to assess these issues holistically is beyond what is possible in New Zealand currently.

Table 14: Embodied energy of main building materials

(after Alcorn (2003) and Jaques (2004))

BUILDING MATERIAL	**kg CO_2/kg material**	**MJ/kg of material**	**MJ/m^3**
Aggregate, general	Negligible	0.10	150
virgin rock	Negligible	0.04	63
river	Negligible	0.02	36
Aluminium, *virgin*	8.00	191	515 700
extruded	8.35	201	542 700
extruded, anodised	9.36	227	612 900
extruded, powder-coated	9.21	218	588 600
Aluminium, *recycled*	0.62	8.1	21 870
extruded	0.72	17.3	46 710
extruded, anodised	0.89	42.9	115 830
extruded, powder-coated	0.73	34.3	92 610
Asphalt (paving)	0.01	3.4	7 140
Bitumen (fuel)	0.02	2.4	2 475
Brick			
brick, new technology	0.14	2.5	5 170
brick, old technology	0.52	7.7	1 580
Bitumen (feedstock)	3.02	44.1	45 420
Cellulose pulp	0.61	19.6	1 057
Cement, average	0.99	6.2	17 550
cement, dry process	0.97	5.8	15 020
cement, wet process	1.02	6.5	20 280
Fibre-cement board	0.54	11.0	
Concrete			
block	0.11	0.94	12.5/unit
block-fill	0.16	1.4	3 150
block-fill, pump mix	0.16	1.5	3 430
precast double T	0.21	1.9	4 546
grout	0.21	1.7	3 496
17.5 MPa	0.11	0.9	2 019
30 MPa	0.16	1.2	2 762
40 MPa	0.19	1.4	3 282
Copper, virgin sheet	7.74	97.6	872 924
virgin, rod, wire	7.48	92.5	827 316
recycled, tube	0.11	2.4	21217

BUILDING MATERIAL	**kg CO_2/kg material**	**MJ/kg of material**	**MJ/m^3**
Glass			
float	1.74	15.9	40 060
toughened	1.74	26.2	66 020
laminated	1.92	16.3	41 080
Gypsum plaster	0.22	3.6	8 388
Insulation			
cellulose	0.14	4.3	146
fibreglass	0.77	32.1	1.03
polystyrene (expanded) polystyrene (extruded)	2.50 2.50	58.4 58.4	1 401 1 868
Paint (acrylic)		88.5	-
paint (alkyd)		98.1	-
Plasterboard	0.42	7.4	7 080
Plastics			
HDPE	0.22	51	7 080
LDPE	3.54	51	91 800
polystyrene, expanded EPS	2.50	58.4	2 340
polystyrene, extruded XPS	2.50	58.4	**1.87**
PVC	4.35	60.9	80 944
Sand	0.07	0.10	230
Steel, recycled		10.1	37 210
reinforcing, sections	0.35	8.9	67 144
wire rod	0.53	12.5	96 544
Steel, virgin, general	0.24	31.3	245 757
Timber, using *pinus radiata*			
air dried, rough-sawn	Negligible*	2.8	1 179
air dried, dressed	“	3.0	1 273
gas dried, dressed	“	9.5	3 998
biofuel dried, dressed	“	4.1	1 732
plywood	0.20	22.2	
MDF	0.36	11.3	8 213