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A Draft Climate Change Sustainability Index for Houses

M. J. Camilleri

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Preface

This is the second of a series of reports prepared on research into the implications of climate change for the construction sector. This report describes the development of a Climate Change Sustainability Index for Houses.

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A DRAFT CLIMATE CHANGE SUSTAINABILITY INDEX FOR HOUSES

BRANZ Study Report SR 95 (2000) **M. J. Camilleri**

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ABSTRACT

The first report of this series (Camilleri, 2000a) identified the many ways that the built environment may be affected by climate change.

In this report the most important effects of climate change on houses, are used as the basis for a Climate Change Sustainability Index (CCSI), which is used to assess the vulnerability of a house to the effects of climate change, and the contribution of a house to climate change from greenhouse gas emissions.

The CCSI consists of two separate numerical ratings: one for impacts on a house (which include summer overheating; coastal and inland flooding; tropical cyclone risk), and another for GHG emissions for space and hot water heating.

A common assessment framework is developed for the CCSI, based on internationally used building environmental assessment methods. The assessment method for each climate change effect is described in detail.

The CCSI can be used to identify the most significant effects of climate change for an individual house, or for many houses in a region. The assessment methodology uses industry standard tools, and readily available information.

Contents

Page No.

1. Introduction 1
   - 1.1 Definition of 'Sustainable Development' 1
   - 1.2 Building Environmental Rating Schemes 3
2. The Climate Change Sustainability Index (CCSI) 10
   - 2.1 The CCSI Framework 10
   - 2.2 Issues Included and Excluded 10
   - 2.3 Credit Allocation 11
   - 2.4 Weighting Between Issues 13
   - 2.5 GHG Emissions 13
     - 2.5.1 Space heating energy 13
     - 2.5.2 Hot water heating 16
     - 2.5.3 Weighting space and hot water CCSI credits 17
   - 2.6 Overheating 18
   - 2.7 Flooding 21
     - 2.7.1 Inland flooding 21
     - 2.7.2 Coastal flooding 22
     - 2.7.3 Weighting coastal and inland flooding CCSI credits 23
   - 2.8 Tropical Cyclones 23
   - 2.9 Final CCSI Weighting 24
3. Conclusions 25
4. References 26

Figures

Page No.

Figure 1. "BREEAM Existing Offices" (BRE, UK).. 5
Figure 2. "BREEAM New Offices" (BRE, UK) 6
Figure 3. "LEED Commercial Building" (US Green Buildings Council)............................... 7
Figure 4. "BREEAM Environmental Standard" for houses (BRE, UK) 8
Figure 5. "BRANZ Green Home Scheme"(BRANZ, 1997).. 9
Figure 6. Maximum summer indoor temperature by solar glazing ratio
and thermal mass level.. 21

Tables

Table 1. 'Environmental Standard' Prior and Bartlett (1995).
Maximum CO_2 emissions (kg / m² / yr). 11
Table 2. BREEAM New Homes version 3/91 credit scheme
(extracted from Prior, Raw, and Charlesworth (1991)).. 12
Table 3. The GBAT generic credit allocation scheme. 12
Table 4. Average numbers of house occupants by number of bedrooms.
Calculated as the weighted average from Table 20 of Census '96
(Statistics New Zealand, 1997), for all households.. 14
Table 5. Heating appliance efficiencies and greenhouse gas emissions
(from Camilleri (2000)).. 15
Table 6. CCSI credits for space heating GHG emissions... 16
Table 7. CCSI credits for water heaters.. 16
Table 8. Efficiencies, and GHG emission factors for various water heaters
(efficiency data from Roussouw (1997)).. 17
Table 9. Emission factors for various fuel types. 17
Table 10. Thermal mass levels for houses (adapted from Bassett, Bishop and
Van de Werff (1990)). 19
Table 11. Summer average maximum temperatures and modifiers. 20
Table 12. CCSI credits for overheating. 20
Table 13. CCSI credits for inland flooding, based on AEP....................................... 22
Table 14. CCSI credits for inland flooding, based on site geography or
flooding occurrence. 22
Table 15. CCSI credits for coastal flooding... 23
Table 16. CCSI credits for tropical cyclone risk.. 23

1. INTRODUCTION

Climate change will impact buildings in many ways. The first report for this programme highlighted greenhouse gas (GHG) emissions, overheating, and coastal and inland flooding as the most important potential impacts of climate change for houses (Camilleri, 2000a).

This report discusses the development of a prototype Climate Change Sustainability Index (CCSI) for houses. The CCSI is intended to be used to assess the severity of the impact of climate change on a house, and the impacts of a house on climate change. The CCSI uses issues highlighted in Camilleri's (2000a) report and assesses them to form two numerical ratings that measure the sustainability of a house in the context of climate change.

'Sustainability' in the context of climate change is defined in the next section as the basis for the CCSI. Following this a variety of Building Environmental Rating Schemes are discussed, and used to assist in the development of the CCSI framework. The climate change impacts included in the index are then discussed, and methods of assessment developed.

This report builds on some issues explored in Camilleri's (2000a) report. Much material is referred to explicitly or implicitly from there. Further information and clarification of many issues is available in that report.

1.1 Definition of 'Sustainable Development'

Sustainability and sustainable development have become buzz-words for the 1990s, and have been applied to everything from the most radical Gaia whole earth concepts to long-term corporate goals (Palmer, 1997). Sustainable development is a difficult concept to define, combining two potentially conflicting notions: development, which involves exploiting natural resources to secure higher living standards; and sustainability, which requires that this development be maintained in the future. In the strict sense, no 'development' can be fully 'sustainable' as it must involve both temporary and permanent alteration of the natural environment.

A widely quoted definition of sustainable development is:

"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs…"

− Our Common Future (1987).

The UK's 1990 Environment White Paper said:

"Sustainable development means living on the earth's income rather than eroding its capital. It means keeping the consumption of renewable natural resources within the limits of their replenishment. It means handing down to successive generations not only man-made wealth, but also natural wealth, such as clean and adequate water supplies, good arable land, a wealth of wildlife, and ample forests."

− Britain's Environment Strategy (1990)

The principles of these definitions are embraced by Agenda 21 (a major outcome of the UN 'Earth Summit[1]' (United Nations, 1999)), which is an action plan for achieving sustainable development. Local Agenda 21 (United Nations, 1999a) is the local implementation of Agenda 21, and has now been adopted by many local and regional councils in New Zealand. Major

[1] The "Earth Summit" was the UN Conference on Environment and Development held in Rio de Janeiro in 1992.

aspects of Agenda 21 include the consideration of ecological impacts (in their widest sense) in economic decisions, the 'precautionary principle', the 'polluter pays' principle, and the direct involvement of all sectors of society.

The vision behind the New Zealand Government's Environment 2010 Strategy is:

"A clean, healthy and unique environment,
sustaining nature and people's needs and aspirations."

The principles of Agenda 21 are reflected in the 11 guiding principles of the Environment 2010 Strategy (Ministry for the Environment, 1997), which are:

1. Sustainable management
2. The precautionary principle
3. Environmental bottom lines
4. Internalisation of external environmental costs
5. Sustainable property rights
6. Least cost policy tools
7. Social costs and benefits
8. Pricing of infrastructure
9. Research, science, and technology
10. Defining the limits of resource use and substitution
11. Protecting our international competitiveness.

These guiding principles provide an example of the broad range of issues involved in sustainable development.

Sustainable development is primarily concerned with the effects of human activities on the natural environment. For the CCSI, the effects of climate change (the natural environment) on houses (human activities) are the primary concern. This is the reverse of the usual definition of sustainability, so for the development of a CCSI, a suitable definition of sustainability must be devised. At the risk of adding yet another definition to the melting pot, sustainability of a building in the context of climate change is defined for the purposes of this report as:

"the ability of a building to withstand the effects of climate change without a significant loss of building performance, relative to the current climate."

Performance is not specifically defined, but could include heating, weather related damage, maintenance costs, or the cost of carbon charges. For example, buildings which are 'sustainable' according to this definition should not have their useful life shortened, nor suffer increased damage as a result of climate change. Thus 'sustainable' buildings do not become more resource hungry with climate change. The effects of climate change on buildings may be positive or negative. Decreased space heating energy is a positive effect, while increased overheating is a negative effect.

This definition incorporates many of the 11 principles of the Environment 2010 strategy. For example, the precautionary approach is taken for possible long-term impacts of climate change. Social costs and benefits may be optimised by a building that is not negatively affected, or reaps the most benefits of climate change.

1.2 Building Environmental Rating Schemes

There are many environmental rating schemes for buildings in use internationally including:

1. BRANZ Green Home Scheme [BRANZ (1997)]
2. GBAT (Green Building Assessment Tool) [Larsson (1998)]
3. BREEAM (Building Research Establishment Environmental Assessment Method) [Prior and Bartlett (1995)]
4. The Office Toolkit [Bishop, Durrant, and Bartlett (1995)]
5. LEED (Leadership on Energy and Environmental Design) [US Green Buildings Council]
6. BEPAC (Building Environmental Performance Assessment Criteria) [Cole (1991)]
7. ATHENA (LCA tool for buildings) [Cole et al. (1996)]
8. The Austin, Texas "Green Builder program" [Seiter et al. (1992)]
9. The City of Scottsdale Green Building Program [City of Scottsdale (1998)].

Five of these schemes are outlined in diagrammatic form (Figure 1 through Figure 5): three of the BREEAM schemes; the LEED scheme for office buildings; and the BRANZ Green Home Scheme. A careful examination shows the broad similarity of the issues considered for each scheme. The issues common to almost all of the outlined schemes are:

1. Energy consumption and / or CO_2 emissions
2. Low or no ozone depletion (i.e. no CFC, HCFC, Halons)
3. Water economy and / or waste water reduction
4. Indoor air quality (low VOX, radon)
5. Use of recycled materials and provision of recycling facilities
6. Waste minimization
7. Control of hazardous waste, and no hazardous materials (e.g. asbestos, lead)
8. Transport (public, carpool, cycling, central location etc)
9. Site ecology (re-use, "brown-field", minimal disturbance).

Issues more relevant to office buildings are:

1. Indoor environment (air, noise, thermal comfort, ventilation)
2. Legionnaires disease for hot water systems and air conditioning.

The major difference between the schemes is the depth of the assessments for each issue. For example the BREEAM New Offices assessments covers 18 issues, while C-2000 covers about 170. The weighting given to each issue also varies, as does the methodology for allocating credits. A thorough and up-to-date overview of building environmental assessment methods may be found in Cole (1998).

These schemes focus on environmental assessment, generally at the design stage of buildings. They cover a range of issues, and award a certificate for designs that fulfil minimum criteria. Early schemes were developed as an initial step in the shift towards more 'sustainable' architecture. They were essentially practical design assistance tools, intended to raise the awareness of the design community and the general public of building-related environmental issues, and the long-term significance of choices made at the design stage. As such, the ratings or credits were not intended to be equivalent between different issues. For example in the BREEAM and BRANZ schemes, the number of credits awarded for energy use is not proportional to the actual energy use, nor the amount of the greenhouse gas emissions. Later schemes (e.g. GBAT) specifically attempt to provide such a consistent scale of credits or ratings.

With further development the schemes have become more sophisticated and cover a wider range of building types. The BREEAM scheme, for example, now has assessment methods for new homes, new offices, existing offices (see Figure 1, page 5), superstores and supermarkets, and has spawned global derivatives including Canada's BEPAC (Cole, 1991) and the BRANZ Green Home Scheme (BRANZ, 1997).

The Office Toolkit (Bishop, Durrant, and Bartlett, 1995), and the Scottsdale Green Building Program (City of Scottsdale, 1998) base their ratings on perceived environmental importance based on scientific research into a building's actual effects on local and global eco-systems and environmental variables. LEED and the early versions of BREEAM had no scientifically based weighting between issues.

There are two methods that implement a building Life Cycle Assessment (LCA): ATHENA™ (Cole *et al*., 1996), and The Office Toolkit (Bishop, Durrant, and Bartlett, 1995). The ATHENA model enables an 'environmental profile' to be generated based on environmental issues, such as: resource usage, energy used, global warming potential, solid waste, and air and water pollution. The profiles were based on a series of investigations and product life cycle studies carried out over several years. ATHENA covers most building types, and can be used to assist in comparing the implications of design alternatives. The UK's Office Toolkit includes both direct and indirect environmental impacts, as well as health and safety aspects. To gauge the relative importance of the different types of environmental impact, the Office Toolkit uses the Swiss-originated 'ecopoint' which was developed in Holland (refer web page: www.pre.nl\). The dimensionless ecopoint is a measure of the severity of the environmental damage, based on society's desire to reduce that damage.

The Green Building Assessment Tool (GBAT) is a so-called second generation method of building assessment (Larsson, 1998). Second generation refers to the 'scalability' of the assessment: it is designed to be used at several levels of detail, from quick assessments to in-depth assessment, to be useful as a design tool, and to be useable for all types of buildings worldwide. This is a very tall order, and time will tell whether the current incarnation of the GBAT is successful. The GBAT was completed for the Green Building Challenge (Larsson, 1998) conference at the end of 1998. One useful feature of the GBAT is its system of assigning credits for assessment items. The baseline is 0 credits for the reference level, up to 5 credits for exceptional performance, and -1 to -2 credits for inferior performance. Criteria for disqualification are also included.

The BREEAM has spawned local variants in several countries, including New Zealand with the BRANZ Green Home Scheme. The BRANZ Green Home Scheme is New Zealand's whole house environmental assessment method, and is used to rate new homes at the design stage (BRANZ, 1997). The scheme is mainly focused on environmental issues, but some health and safety issues are also addressed. Although based on the UK's BREEAM scheme, it is greatly modified, being more descriptively based and covering a wider variety of issues. Fourteen environmental, health and safety issues are considered, based on life cycle principles. The scheme will be continually developed (incorporating attributes such as environmental indicators), with a version for office buildings planned in the near future. Some aspects of the CCSI will be considered for inclusion in future revisions of the BRANZ Green Home Scheme. The CCSI GHG emissions assessment could replace the current qualitative assessment of heating, and the overheating issue used to further emphasise the importance of controlling the summer heat in the most vulnerable regions.

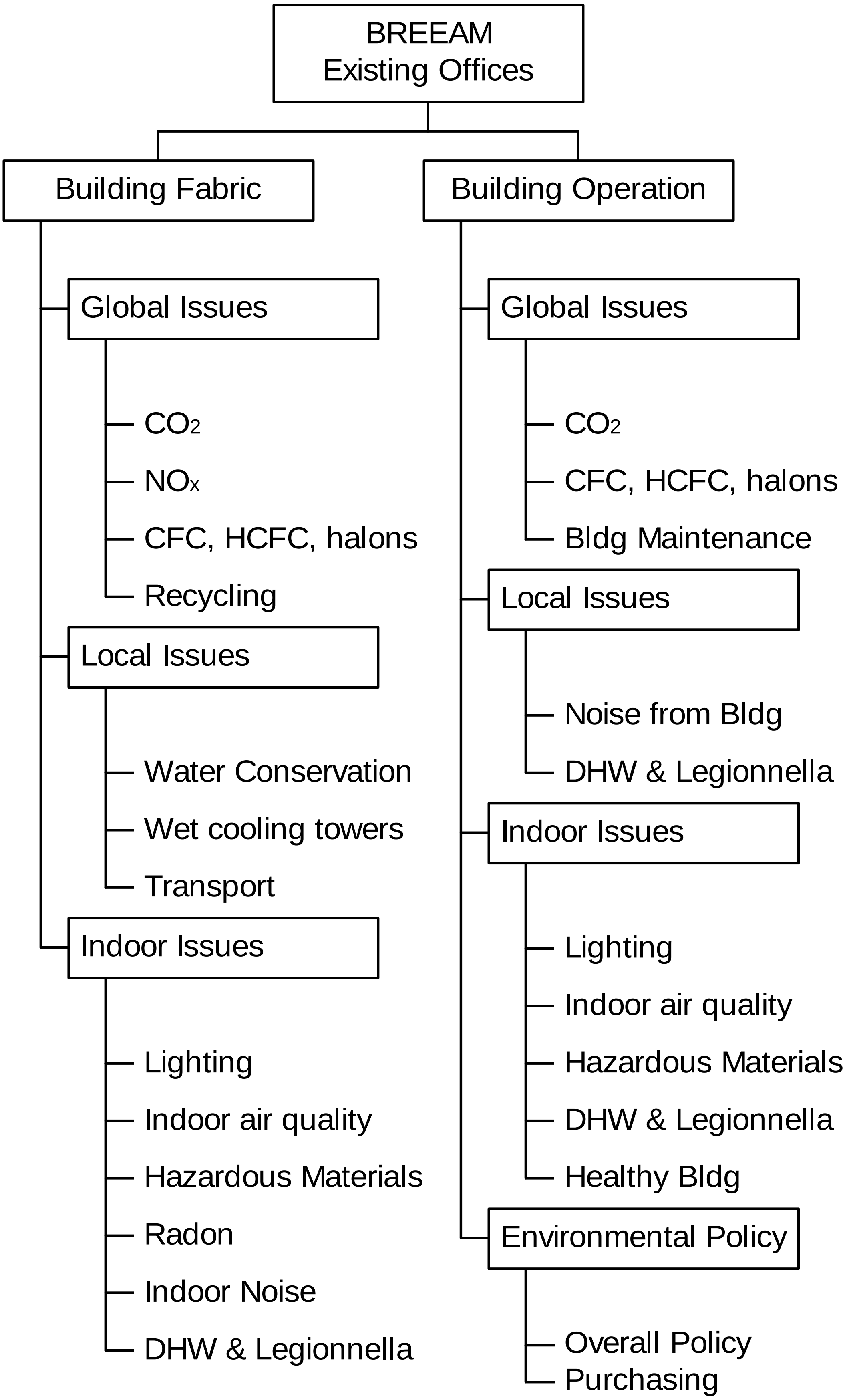

Figure 1. "BREEAM Existing Offices" (BRE, UK)

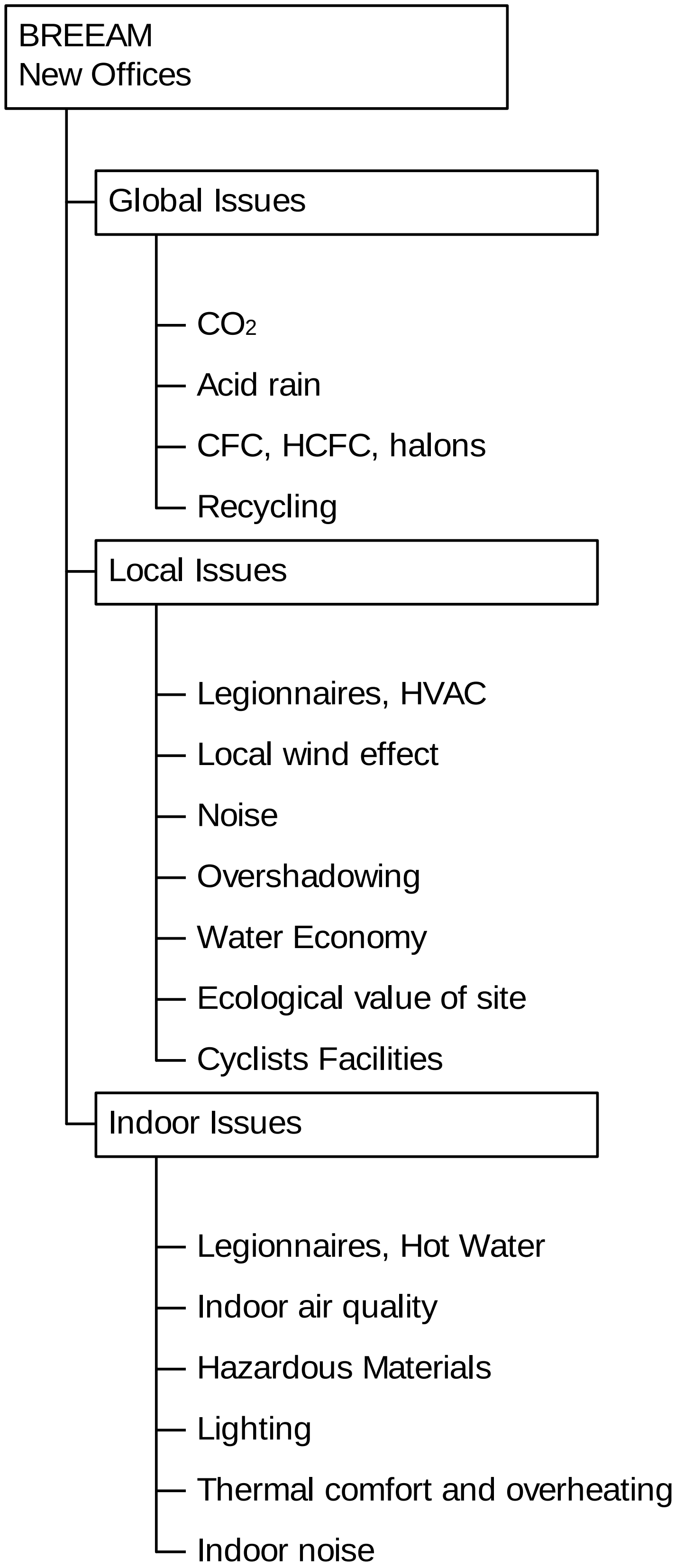

Figure 2. "BREEAM New Offices" (BRE, UK)

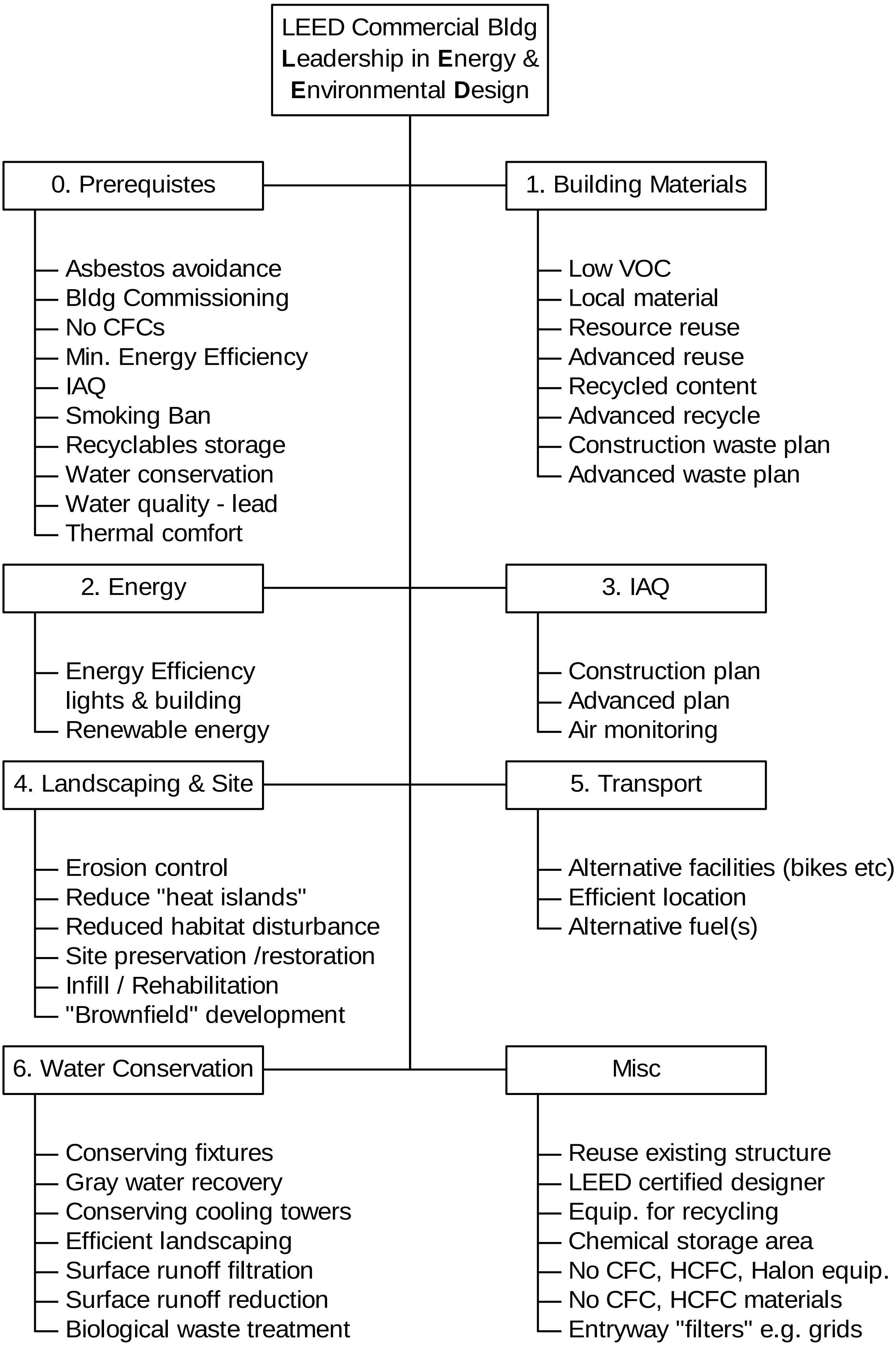

Figure 3. "LEED Commercial Building" (US Green Buildings Council)

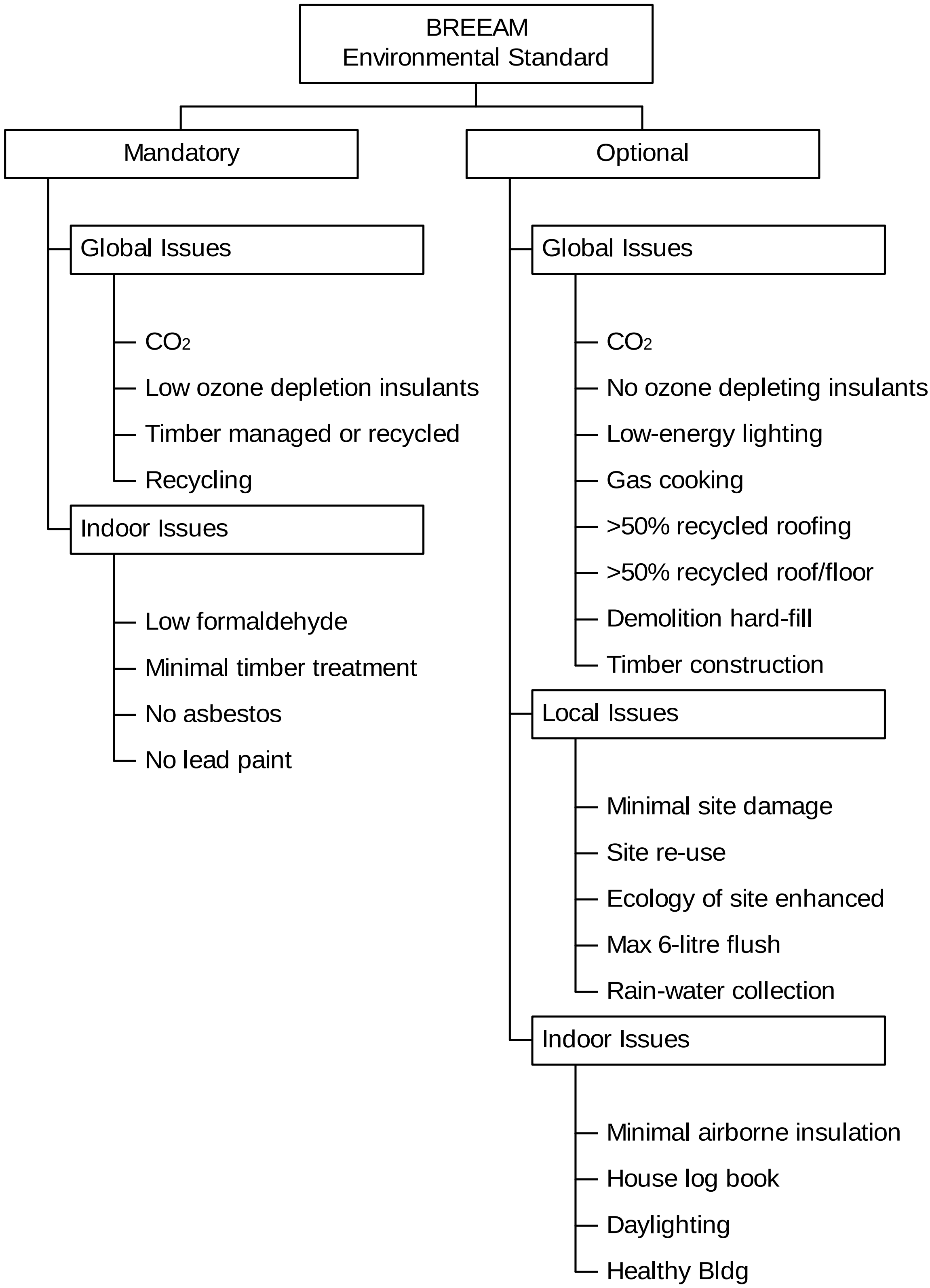

Figure 4. "BREEAM Environmental Standard" for houses (BRE, UK)

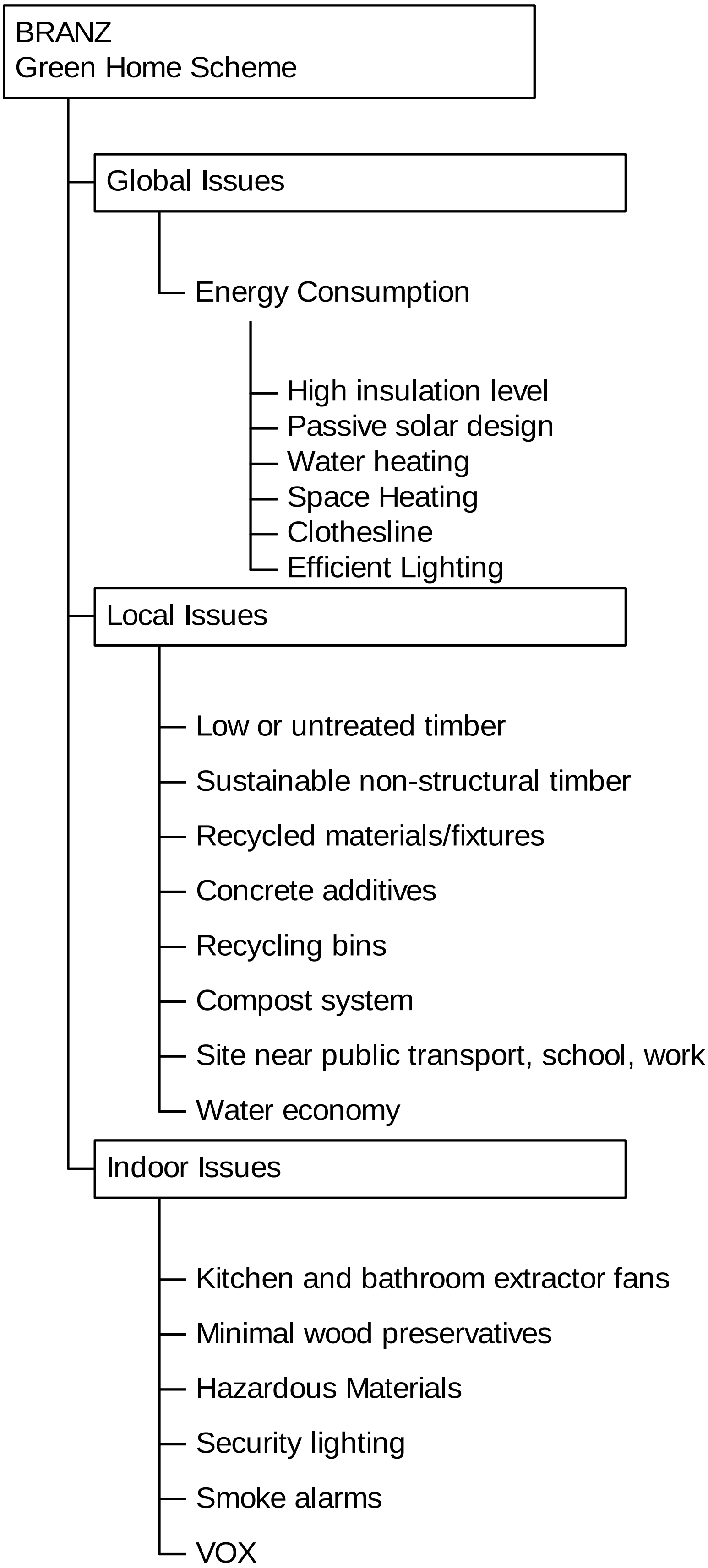

Figure 5. "BRANZ Green Home Scheme"(BRANZ, 1997)

2. THE CLIMATE CHANGE SUSTAINABILITY INDEX (CCSI)

2.1 The CCSI Framework

The basic form of the assessment methods described earlier, and the issues covered provide a useful starting point for the structure of the CCSI, which is developed here by selecting the elements most appropriate to New Zealand from these schemes. Credit allocation and weighting are discussed later in this section.

Most of these schemes assess energy use and/or CO_2 emissions, with some considerations of resource use, and also aspects of occupant comfort, health, and safety. Many like BREEAM (Prior and Bartlett, 1995) include an assessment of GHG emissions for energy use, or even a full life-cycle assessment of environmental effects (ATHENA (Cole *et al*., 1996)). The BRANZ Green Home Scheme includes issues of passive solar design and thermal design, which is an indirect assessment of vulnerability to temperature change. Others consider water conservation (BREEAM, LEED (US Green Buildings Council)), useful if climate change brings water restrictions, or site runoff (LEED), useful if climate change brings increased extreme rainfall.

None of the methods were designed to assess the effect of climate change *on* the building itself, which is the major goal of the CCSI. The closest any get is in the consideration of energy efficiency and passive solar design, which if incorporated into a building may mitigate the effects of increased temperatures. Therefore only a few specific issues from each scheme are relevant to the CCSI.

The general issues highlighted in the previous section that have some relevance to the impact of a building on climate change are:

1. Energy consumption and / or CO_2 emissions

2. Low or no ozone depletion (i.e. no CFC, HCFC, Halons).

Issues indirectly relevant to the impact of a building on climate change are:

1. Transport (public, carpool, cycling, central location etc)

2. Use of recycled materials and provision of recycling facilities

3. Waste minimisation.

2.2 Issues Included and Excluded

Some of the issues quantified in the first report (Camilleri, 2000a) are included in the CCSI. The issues included here are those that had a reasonable certainty of occurring with climate change, and also had significant impacts. These are: overheating; tropical cyclones; and both coastal and inland flooding. Space heating and hot water heating energy GHG emissions are also considered separately.

Issues from other assessment methods that were not included were transport and location (as they are strongly linked to occupant behaviour), and recycling and waste minimisation in the construction process (as the construction GHG emissions are generally much smaller than occupancy emissions).

The methods in ATHENA (Cole *et al*., 1996), GBAT (Larsson, 1998) and other tools for assessing the embodied energy and embodied GHG emissions would be of great use to the New Zealand sustainability index. However, at the moment the assessment is not feasible for New

Zealand as the GHG emission information is not fully compiled, and does not yet extend to manufactured building components, let alone whole buildings. Currently, any assessment of embodied energy and GHG emissions would be a very complex and involved process. If the proportions of occupancy and construction GHG emissions are similar to the proportions for energy reported by Jaques *et al* (1997), then it is likely that the occupancy GHG emissions will be much greater than the construction emissions for many houses. So omitting construction emissions from the CCSI at this stage should not seriously compromise the assessment. Therefore construction embodied energy and GHG emissions are not be included in the CCSI at this stage.

These issues are those that are most relevant to New Zealand. Different issues may be appropriate for different countries, depending on their individual scenarios of climate change, and the vulnerability of the buildings to the effects of climate change. For example, coastal flooding would not be an issue for land-locked countries.

2.3 Credit Allocation

The credit scoring systems for the assessment methods provide useful precedents for the CCSI. Most of the schemes have a different number of credits available for each issue. How the credits are awarded on the basis of building performance varies from scheme to scheme.

The LCA type methods base the relative credits within each issue on a mathematical quantity (e.g. Global Warming Potential (GWP), volume of waste water, or amount of fossil fuel used). The number of credits is in a linear relation to the effect/amount, i.e. twice the GWP gives twice the credits.

Some of the non-LCA methods (BREEAM (Prior and Bartlett, 1995), LEED (US Green Buildings Council)) award a set number of credits for exceeding a certain threshold or baseline (see Table 1). The thresholds are generally based on current normal building performance. In the case of the BEPAC assessment, the credits awarded are influenced by the effort and cost of achieving a standard much higher than industry norms. The unit of measurement (i.e. emissions per unit area, per building, or per occupant) are an important part of the assessment. These are examples of a linear or non-linear zoned system.

For some issues in the non-LCA methods, credits are awarded simply on the basis of the presence of a particular building feature or system, for example gas cooking in the BREEAM Environmental Standard.

The BREEAM Environmental Standard GHG emissions credits for home energy are presented as an example (Table 1). Only 1 or 2 credits are awarded in the current version of the scheme, so it is only a small component of the minimum 22 credits required for the scheme.

Table 1. 'Environmental Standard' Prior and Bartlett (1995). Maximum CO_2 emissions (kg / m² / yr).

Floor Area (m²)	1 credit	2 credits
<50	31	21
50-100	30	19
>100	29	17

A previous version of the assessment method had a finer division of credits (Prior, Raw, and Charlesworth, 1991), starting at GHG emission levels anticipated by a modern house built to the UK building code (Table 2). The levels were related to the amount (expense, effort) of energy efficient features and technology needed to achieve the GHG emission levels, and as such are not mathematically related to the actual quantity of emissions. The reason for the change may have been to avoid problems of giving large houses more credits than small houses, as for the same quality of building envelope, a larger house will have a lower heating requirement, and hence lower greenhouse gas emissions.

Table 2. BREEAM New Homes version 3/91 credit scheme (extracted from Prior, Raw, and Charlesworth (1991)).

GHG emissions (kg CO_2 / m²/year)	credits
<36	6
36-45	5
46-55	4
56-70	3
71-90	2
91-105	1

There are many possible choices for allocating credits for the CCSI. For example, consider the possibilities for credits for GHG emissions: a straight linear relationship; a non-linear relationship, a zoned system with maximum credits; or scale the emissions according to the size or expected occupancy of the house. Each approach has advantages and disadvantages. A linear scaling fairly represents the relative emissions, but labels a large house as less sustainable than a small house, even though the emissions per occupant may be lower in the larger house. Capping the credits at some maximum value does not penalise houses with catastrophically high emissions. Not capping the credits could allow one particularly good or bad aspect of a house to dominate the assessment. Scaling according to the emissions per unit of floor area can unfairly credit wastefully large houses.

A non-linear, capped system was adopted for the CCSI, as it appears to produce the fewest problems in general. The GBAT (Larsson, 1998) credit allocation system (Table 3) appears to have some additional desirable features beyond those of other systems. It does not reward ‘Normal’ performance, penalises poor performance, and has plenty of credits available for enhanced performance. In contrast, most other schemes do not penalise poor performance, they just award 0 credits (or perhaps make the item compulsory). The CCSI is intended to ‘warn’ of those houses that are vulnerable to climate change, and reward homes that make a low relative contribution to climate change, so having both positive and negative credits is a valuable feature. The 0 credits for normal performance provides a convenient baseline or reference level for normal risk or performance.

Table 3. The GBAT generic credit allocation scheme.

Performance	credits
Significantly inferior	-2
Inferior	-1
Normal	0
Enhanced	1-4
Exceptional	5

The credit criteria for each issue will be described within the corresponding discussion.

2.4 Weighting Between Issues

The weighting systems for the assessment methods listed in Section 1.2, page 3, also provide some precedent for the CCSI. Most of the schemes (including BREEAM (Prior and Bartlett, 1995) and LEED (US Green Buildings Council)) provide a single overall number for the assessment. In the BEPAC scheme the weighting is explicit, as each issue is given from 0-10 credits and then multiplied by some factor for the overall rating. In other schemes the weighting is implicit as the credits are simply added, and the total available number of credits is different for each issue, even if there were no intention of weighting the different issues.

The LCA type methods (ATHENA and The Office Toolkit) use a mathematical weighting within some issues (e.g. GHG emissions scaled by the GWP for each gas), and then weighted using the formal normalisation step. The normalisation step for The Office Toolkit is based on the eco-points system. In this system a certain quantity of resource use, pollution emission, or health hazard is given a number of eco-points. These are then simply added to give an overall number of eco-points for the building.

The issue of weighting between each of the climate change impacts is important. The default option is to assign them equal weighting. Assigning a different weighting to each impact implies that one impact is more important than another. At this stage there is no justification for unequal weighting. The author is unaware of any sensible methodology that could be used to weight GHG emissions against, for example, the building damage and social cost of increased flooding. As a consequence the ratings for GHG emissions are kept separate, and the flooding, overheating and tropical cyclone ratings are combined using equal weight.

As the CCSI is not a high precision assessment, the final combined rating will only have a few divisions. The individual credits for each impact will be averaged to give an overall CCSI value for the house of between -2 and 5 (the same scale as each individual assessment), for a total of 8 integer ratings. See Section 2.9, page 24 for the final weighting scheme.

2.5 GHG Emissions

The GHG emissions from a house contribute directly to climate change. Any level of emissions is potentially harmful. Only two major sources of GHG emissions from houses are considered: space heating and hot water heating. These should form the bulk of GHG emissions during occupancy of a house, and are strongly influenced by the design of the house and fixed appliances. Lighting has not been included in the CCSI for houses as it is a much smaller proportion of the total household energy use than space and water heating, and is highly dependent on occupant behaviour. Embodied GHGs are not considered, as there is no convenient methodology or data source available yet for New Zealand, and most of the GHG emissions occur during occupancy. They may be included in the future.

The BRANZ Green Home Scheme (BRANZ, 1997) awards credits for efficient water and space heating, but takes no account of their actual GHG emissions. The scheme outlined here attempts to account for these GHG emissions, and will be considered for inclusion in future revisions of the BRANZ Green Home Scheme.

2.5.1 Space heating energy

Background

The amount of energy used for space heating is determined by a combination of occupant demand and the thermal performance of the house. However, the CCSI can only deal with the thermal performance of the house. By assessing the thermal performance of the house, and the

GHG emissions of the heating system, a baseline for energy use and GHG emissions can be established for the house. This will be used for the CCSI.

The CCSI is intended to measure both the impact of the environment on the house, and the impact of the house on the environment. To avoid the problems inherent in gross emissions or emissions scaled to house area, the emissions are scaled according to the expected number of occupants.

The number of occupants derived on the basis of the number of bedrooms is available from the 1996 Census (Statistics New Zealand, 1997). In Table 4, page 14, the average number of occupants for a house by the number of bedrooms is given, calculated from the weighted mean of the census data. The mathematical relationship:

$$\text{No. of Occupants} = (\text{No. of Bedrooms} + 1) \times 0.69$$

is a good approximation to the actual figures for six or fewer bedrooms. For the CCSI use either the above formula, or the exact averages from Table 4, page 14.

Table 4. Average numbers of house occupants by number of bedrooms. Calculated as the weighted average from Table 20 of Census '96 (Statistics New Zealand, 1997), for all households.

Number of Bedrooms	1	2	3	4	5	6	7	8+
Average No. of Occupants	1.4	1.9	2.8	3.6	4.3	4.6	3.3	2.7
(No. bedrooms + 1)*0.69	1.38	2.07	2.76	3.45	4.14	4.83	5.52	6.21

The reference level for space heating energy is open to debate. By setting an absolute physical quantity, well insulated houses in cold regions of New Zealand may rate the same as poorly insulated houses in warm regions. On the other hand, the CCSI is intended in part to prompt people to reduce GHG emissions, and rating a poorly insulated house in a warm region with 2 or 3 CCSI credits sends the wrong message. However, the atmosphere does not care how well insulated a house is, only how much GHGs are emitted, so for the CCSI absolute levels of GHG emissions are rated.

Method

Calculate the annual heating energy requirement for the house using the ALF 3 method (Stoecklein and Bassett, 1999), using the 7-9 am and 5-11 pm heating schedule, and 18°C temperature setpoint. Convert the heating energy consumption to kg CO_2 equivalent using the appropriate conversion factor for the house's heating appliances from Table 5 page 15. If there is a mixture of heating appliances then use the average emission factor. Divide by the assumed number of occupants, equals (number of bedrooms + 1)× 0.69, to arrive at the GHG emissions per person per year. Then convert to CCSI credits using Table 6, page 16.

e.g. Calculate 4500 kWh per year for an Auckland house. The heating type is Natural Gas central heating, which has a conversion factor of 0.29 kg CO_2 per kWh. So the yearly emission is:

$$4500 \times 0.29 = 1305 \text{ kg } CO_2 \text{ equivalent per year}$$

The house has 4 bedrooms, and so is assumed to house 3.6 people, so the emission per person is

$$1305 \div 3.6 = 363 \text{ kg } CO_2 \text{ equivalent per year}$$

Which converts to 2 CCSI credits using Table 6, page 16.

Table 5. Heating appliance efficiencies and greenhouse gas emissions (from Camilleri (2000a)).

Fuel	Heater Type	Fuel Emission Factor (kg CO_2 eq. /kWh)	Efficiency	kg CO_2 equivalent / kWh heating output
Electricity[2]	Air conditioner	0.64	1.9	0.34
Electricity	Ducted heat pump	0.64	1.68	0.38
Electricity	Resistance	0.64	1	0.64
Electricity	Floor	0.64	0.9	0.71
Electricity	Night store[3]	0.64	0.8	0.8[3]
Electricity	Ceiling	0.64	0.6	1.07
Natural gas	Unflued	0.19	0.81	0.23
Natural gas	Flued	0.19	0.8	0.24
Natural gas	Central heating	0.19	0.66	0.29
LPG	Unflued	0.22	0.81	0.23
LPG	Flued	0.22	0.8	0.24
LPG	Central heating	0.22	0.66	0.29
Diesel	Central heating	0.25	0.42	0.59
Coal	High eff. double burner	0.36	0.8	0.44
Coal	Basic double burner	0.36	0.65	0.55
Coal	Pot belly	0.36	0.35	1.01
Coal	Free-standing metal fire	0.36	0.25	1.42
Coal	Open fire	0.36	0.15	2.37

Note: Wood has not been included as recently harvested wood releases carbon that was stored in the wood, having no net effect on atmospheric CO_2 levels. There are CO_2 emissions for wood production and supply, though these are not known accurately, and will likely vary greatly across New Zealand. The net emissions are probably much lower than for coal.

Credit Allocation

The reference level of 0 CCSI credits is set at about the level of GHG emissions for a person in a well insulated house in Wellington or Christchurch, in one sense a national 'spatial' average. The lowest level of -2 CCSI credits is at about the level for an uninsulated house in Invercargill, and should be approximately the highest energy use in New Zealand for a normal type of house. The highest level of 5 CCSI credits is awarded to houses with no GHG emissions. To achieve this a house must use zero-emission energy for space heating, or require no dedicated space heating. Passive solar heating is one example of zero-emission heating. Wood in general is not considered to be zero emission as GHGs are emitted for management, processing, and transport.

[2] Emissions for electricity used for heating (except night rate) have been calculated as the marginal emissions of thermal power stations, because at the time of day of peak heating demand (evenings) thermal stations produce a large fraction of the total electricity, and any reduction in demand would reduce thermal station output.

[3] The night store heater is assumed to have the same emissions as a resistance heater, as the marginal electricity emission factor at night is generally that of thermal power stations at 0.64 kg CO_2 eq/kWh.

Table 6. CCSI credits for space heating GHG emissions.

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

2.5.2 Hot water heating

Background

The use of hot water is determined by occupant demand, which cannot be accounted for by the CCSI. However, the relative amount of GHG emissions is determined by the type of hot water heater installed in the house. The individual hot water heater types have been given a CCSI rating according to their GHG emission factors.

Method

The CCSI credits are based solely on the GHG emissions for the hot water heating appliance in the house, as explained in the following paragraphs.

Credit Allocation

The reference level is an ‘A’ grade electric hot water cylinder, gaining 0 CCSI credits. The night store cylinders have been assumed to have ‘A’ grade insulation standards, and to use an unspecified combination of hydro and thermal electricity, so they have been rated at 1 credit, as they should have slightly lower emissions than an ‘A’ grade electric cylinder. All ‘B’ or lower grade cylinders rate -1 credits. The solar/electric cylinders have been rated at 4 credits as they do not use much, if any electricity, during the daytime, and so should make less use of peak evening electricity than a heat pump. Only solar water heating systems with no GHG emitting backup are awarded 5 CCSI credits.

Electricity is assumed to be generated by thermal stations because most electricity demand for hot water cylinders occurs during peak times when hydro stations are fully utilised, therefore any increase or decrease in electricity would come from thermal stations with an emission of 0.64 kg /kWh.

Table 7. CCSI credits for water heaters.

GHG emission factor (kg CO_2 / useful kWh /yr)	CCSI credits
0.00	5
<0.25	4
<0.33	3
<0.50	2
<0.65	1
<0.75	0
<0.90	-1
≥0.90	-2

Table 8. Efficiencies, and GHG emission factors for various water heaters (efficiency data from Roussouw (1997)).

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

Table 9. Emission factors for various fuel types.

Fuel Type	Emission Factor kg CO_2 equivalent/kWh
Coal	0.35
CNG	0.19
LPG	0.22
Thermal Electricity	0.64
Average Electricity	0.10
Diesel	0.25

2.5.3 Weighting space and hot water CCSI credits

The space and hot water heating CCSI credits are combined by weighting their CCSI credits by their respective GHG emissions, using the formula:

$$CCSI_{GHG} = \frac{(CCSI \cdot GHG)_{space} + (CCSI \cdot GHG)_{water}}{GHG_{space} + GHG_{water}}$$

This weighting ensures that GHG emissions from space and water heating are given equal weight.

[4] See Footnote 3

The actual GHG emissions for the water heating are calculated by multiplying 950 kWh per person per year by the GHG emission factor for the water heating appliance. This figure of 950 kWh per comes from the EERA database (Roussouw, 1997), which uses an average hot water consumption figure of 2600 kWh useful heat per household per year. From the census, the average occupancy of a house is 2.75 people (Statistics New Zealand, 1997), so the average hot water consumption is about 950 kWh useful heat per person per year. Results of the HEEP survey are similar (Stoecklein and Isaacs *eds*., 1998), showing that hot water consumption is about 1000 kWh per person per year. The hot water usage is of similar magnitude to the space heating requirement, and so cannot be dismissed.

Fractions are preserved for the overall CCSI weighting. This weighting ensures that GHG emissions from space and water heating are treated equally, and also makes it possible to get a rating above 4 if either the space heating or water heating rates 5 CCSI credits.

2.6 Overheating

Background

There are some general design and thermal principles which govern a house's vulnerability to overheating. The outdoor temperature is the starting point for overheating. Without internal heating or cooling, a house will be a few degrees above the outside temperature most of the time. Overheating is caused by excess heat (primarily from solar radiation), but is mitigated by thermal mass and ventilation. Excessively large, inadequately shaded windows orientated to the N, NW, NE, and W can permit entry of excessive insolation. West-facing windows are particularly problematic, as they allow low angle afternoon and evening sun to enter the house when the air temperature is already high. If the house has low thermal mass and low ventilation rates it can quickly become very hot. With higher thermal mass, the internal temperature can still rise, but more slowly and not to as high a temperature as a low mass house of similar layout. Ventilation can at best reduce the indoor temperature to the same as the outdoor temperature, though increased air-movement improves comfort by increasing the effectiveness of sweating. Overheating is more of a problem in summer, but can occur at any time of the year.

Method

The overheating assessment is based on the methods developed by Jaques (2000). The factors for rating a house are:

1. Solar window area
2. Insulation level
3. Thermal mass level.

The risk of overheating for a particular house is assessed using the following method, based on the results of a companion report (Jaques, 2000). In that report the overheating of houses was modelled along the effect on overheating of a range of variables, including increasing outside air temperatures, climate zones, insulation, thermal mass, window areas and ventilation. The risk of overheating in houses was summarised into a simple method that predicted the likely maximum sustained summer indoor air temperature, based on the solar window area[5] to floor area ratio (SWR), with corrections for climate, insulation and thermal mass. The overheating risk is established from these variables, as detailed in this section.

[5] The solar window area is the area of glazing facing directions SW through N through E that is exposed to the direct summer sunshine (Dec-Feb inclusive).

The overheating risk is estimated in three steps:

- Step 1: Estimate Thermal Mass
- Step 2: Estimate SWR
- Step 3: Find overheating risk

Step 1: Estimate Thermal Mass

The thermal mass is estimated from the building construction type as specified in Table 10. Most New Zealand houses are timber framed, with a timber or carpeted floor, and have a thermal mass level of about 0. Other construction types may have a larger thermal mass.

Table 10. Thermal mass levels for houses (adapted from Bassett, Bishop and Van de Werff (1990)).

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

Step 2: Estimate SWR

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

Step 3: Estimate maximum indoor summer temperature

Use Figure 6 to look up the likely maximum summer temperatures. To do this, find the solar window area ratio on the horizontal axis, go up to the line with the thermal mass level from above, then find the corresponding maximum temperature on the vertical axis. Once the maximum summer temperature is found, apply the following modifiers for insulation level and climate.

<u>For insulation level:</u>

- Uninsulated: +1°C
  (most pre 1978 houses)
- Insulated to approx level of NZS 4218:1996: +0°C
  (most post-1978 houses)
- Insulated well in excess of NZS 4218:1996: −1°C
  (only superinsulated houses)

For climate location:

Table 11. Summer average maximum temperatures and modifiers.

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

Credit Allocation

To find the CCSI credits for overheating, match the maximum indoor summer temperature from above into the following table.

Table 12. CCSI credits for overheating.

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

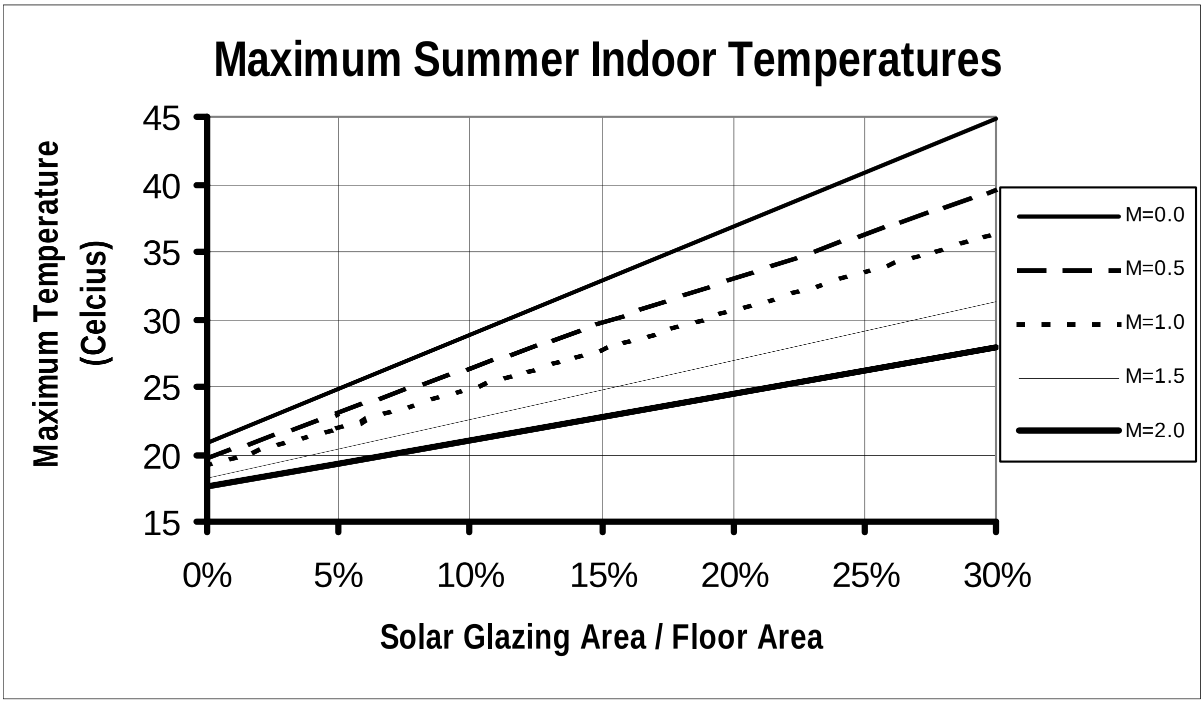

Figure 6. Maximum summer indoor temperature by solar glazing ratio and thermal mass level.

2.7 Flooding

The acceptable level of risk for flooding according to the New Zealand Building Code (BIA 1995) is a 2% annual risk of over-the-floor flooding (a 2% annual exceedence probability (AEP)). As noted in the previous report (Camilleri, 2000a) many houses already have a higher risk than this.

Inland and coastal flooding are to be assessed separately, and then combined to give an overall flooding rating for the CCSI. The lowest credit rating for coastal or inland flooding is then used for the overall CCSI rating.

Actual flooding AEPs are used to assign the CCSI credits. If AEPs are not available, an alternative method is used based on the flooding detectability criteria developed by (Camilleri, 2000a). By this criterion, if a house has been flooded two or more times in its 'lifetime' it is very unlikely that the actual flooding AEP is 2% or less. The 'lifetime' will be problematic for many houses: some will have not been around for long enough to have any flooding history, or the area's history may be unknown. No provision has been made for assessing risk based on different 'lifetimes' at this stage.

2.7.1 Inland flooding

The inland flooding AEP is expected to double by 2030, and quadruple by 2070. Therefore, only houses with a <0.5% AEP already will still be within the acceptable risk by 2070 in the worst case scenario.

Table 13. CCSI credits for inland flooding, based on AEP.

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

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

Table 14. CCSI credits for inland flooding, based on site geography or flooding occurrence.

Criteria	CCSI Credits
Never flooded, not on floodplain, not near river, lake, or urban drainage area	5
Never flooded, but in urban drainage area	4
Never flooded, but near river	3
Never flooded, but on floodplain	2
Never flooded, but nearby areas flooded	1
Never flooded, but adjacent properties flooded	0
Flooded once	-1
Flooded twice	-2
Flooded more than twice	X

2.7.2 Coastal flooding

Quite how the AEPs for coastal flooding will change with climate change will depend on the individual site. This is not known for most locations around New Zealand. If current AEPs are known then these are used to assign CCSI credits on the same scale as for inland flooding (see Table 13). If they are not known use the criteria in Table 15 modified for the exposure of the coast.

Table 15. CCSI credits for coastal flooding.

Criteria msl = mean sea level	CCSI Credits
more than 20m above msl and more than 500m from shore	5
within 10m of msl and <500m from shore	4
within 6m of msl	3
within 5m of msl	2
within 4m of msl	1
within 3.5m of msl	0
flooded once or within 3m of msl	-1
flooded twice	-2
flooded more than twice	X

2.7.3 Weighting coastal and inland flooding CCSI credits

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

2.8 Tropical Cyclones

The risk of changes in the incidence and intensity of tropical cyclones in New Zealand cannot yet be determined from climate change scenarios. However, the potential for damage to New Zealand houses with even small increases in tropical cyclone activity is so large that it is included in the CCSI. The North Island faces the direct risk from tropical cyclones, and Northland and the East Coast are particularly vulnerable because of the wind directions associated with cyclones. The risk is less for the lower North Island as cyclones generally weaken after passing over land and lower latitudes. Cyclones are extremely unlikely to penetrate as far as the South Island.

Table 16. CCSI credits for tropical cyclone risk.

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

2.9 Final CCSI Weighting

The CCSI for climate change impacts is defined as the average credits from the overheating, tropical cyclones, and the weighted coastal and inland flooding credits as per section 2.7.3, page 23. In this way there is equal weighting for overheating, cyclones and flooding. In addition, if the flooding credit is X for extreme, the entire rating is X.

The CCSI for GHG emissions is the average rating for space heating and hot water heating weighted according to section 2.5.3, page 17.

<u>CCSI Impacts</u>

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

<u>CCSI GHG Emissions</u>

Space Heating Water Heating	→	**Heating**	___

3. CONCLUSIONS

A framework for a 'Climate Change Sustainability Index for Houses' (and buildings generically) has been designed. Internationally used building environmental assessment methods have been used as a reference point for the framework.

The framework includes assessment of GHG emissions, the susceptibility to increased overheating, susceptibility to increased flooding risk, and exposure to potential increased tropical cyclone activity. Only those factors that were identified as both likely and significant in Camilleri (2000a)) previous report were included, with the addition of tropical cyclones, which are included because the potential for damage is so large. The rating gives two numerical ratings of the sustainability of houses in the face of climate change: one for impacts on the house, and one for GHG emissions. The weighting between factors is equal, and an alphabetical X indicates extreme risk in the case of flooding.

The CCSI for impacts is calculated using simple design factors and local climate for overheating, current flooding risk and/or geographical factors for coastal and inland flooding, and geographical factors for tropical cyclones. The GHG CCSI rating is assessed using the ALF3 method (adapted for GHG emissions).

The index is suitable for use nationwide, and the results can be mapped readily.

The framework is applicable to buildings in general, and will be used for a CCSI for Office Buildings in a future report. Comments and suggestions are invited.

4. REFERENCES

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

BIA 1995. *New Zealand Building Code Clause E1 Surface Water.* Building Industry Authority. Wellington.

Bishop, Tony, Helen Durrant, and Paul Bartlett. 1995. *The Office Toolkit.* Building Research Establishment. UK.

BRANZ. 1997. *Green Home Scheme: Homeowners Guide,* First edition August 1997. Building Research Association of New Zealand. Judgeford.

Britain's Environment Strategy. 1990. *This Common Inheritance, Britain's Environment Strategy.* Cm1200, HMSO, 1990. ISBN 0-10-112002-8.

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

City of Scottsdale. 1998. *Scottsdale Green Building Program.* City of Scottsdale. Arizona. USA.

Cole, R. BEPAC - *Building Environmental Performance Assessment Criteria.* The Environmental Research Group. University of British Columbia. 1991.

Cole, R. *et al.* 1996. ATHENA™. *An environmental assessment of building designs.* Forintek Canada Corporation.

Cole, Raymond J. 1998. *Emerging trends in buildings environmental assessment method.* Building Research and Information. Vol 26, no. 1, pp 3-16.

DeLaHunt, Mary Jane. 1985. SUNCODE-PC: A program user's manual. Program and original manual written by Terry Wheeling and Larry Palmiter. Ecotope, Incorporated.

Donn, Michael, and Ian Van Der Werff. 1990. *Design guidelines: Passive solar in New Zealand.* Report RD883. Ministry of Commerce. Wellington. ISBN 0114-8869.

EECA, 1994. *Design for the Sun*. Volume 2 Reference Manual. Energy Efficiency and Conservation Authority. Wellington.

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

Jaques, R., Bennett, A., Sharman, W., and Isaacs, N. 1997. *Legislative opportunities to reduce CO2 emissions in New Zealand.* Second International Conference Buildings and the Environment, June 1997, Paris.

Larsson, Nils. 1998. Green Building Challenge '98: International strategic considerations. Building Research and Information. Vol. 26. No. 2, pp 118-121.

LEED Commercial Building. US Green Buildings Council website http://www.usgbc.org

Ministry for the Environment. 1997. *1997 Stocktake of the Environment 2010 Strategy.* Ministry for the Environment, Wellington.

Our Common Future. 1987. *The Report of the World Commission on the Environment and Development* (the "Brundtland Commissions"). Oxford University Press, 1987. ISBM 0-19-282080-X.

Palmer, Henry. 1997. "Roll *over, Malthus...".* New Scientist. 22 November 1997. pg 64.

Prior, J. J., G. J. Raw, and J. L. Charlesworth. 1991. BREEAM/Hew Homes, Version 3/91: *An environmental assessment for new homes.* BRE, Garston, Watford, UK..

Prior, Josephine J., and Paul B. Bartlett. 1995. *Environmental Standard: Homes for a greener world.* Building Research Establishment Report BR 278. Garston, Watford.

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

Seiter, R. *et al.* 1992. *Green Building Guide - A sustainable approach.* Green Builder Program. Austin, Texas.

Statistics New Zealand. 1997. Census 96: 1996 New census of population and dwellings. Statistics New Zealand. December 1997. Wellington. ISBN 0110-8700.

Stoecklein, Albrecht, and Nigel Isaacs (editors). 1998. *Energy use in New Zealand houses – report on the household energy end use project (HEEP) Year 2.* Energy Efficiency and Conservation Authority. Wellington.

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

United Nations. 1999. Agenda 21 website. Last version cited 31/08/1999. http://www.un.org/esa/sustdev/agenda21.htm

United Nations. 1999a. Sustainable Development National Information. Website http://www.un.org/esa/agenda21/natlinfo/about.htm.