Environmental Impacts of Multi-Storey Buildings Using Different Construction Materials

A report written under contract to the New Zealand Ministry of Agriculture and Forestry.

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Postscript

This report was drafted during the 2007/08 year.

Research carried out by Scion early in 2009 using Life Cycle Assessment (LCA) studies produced new environmental impact datasets specifically for New Zealand building materials. These new datasets, together with more recent information on decomposition in landfills, have been used to substantially revise and update the LCA of the buildings in Chapter 6, as well as the discussions and conclusions.

A recent change of Government in New Zealand has announced that there will be a review of the Emissions Trading Scheme legislation and some policies associated with moving NZ towards being more sustainable. This report has not been revised to take account of these events.

Contents

Glossary

CO_2 stored – refers to the CO_2 stored in non decomposed wood that has been disposed of in landfill.

Embodied energy – refers to the energy required to make a product, which includes: raw material acquisition and processing, energy production, transport, and product manufacturing, i.e. “cradle to gate”.

End of life energy – refers to the energy associated with the disposal of a material at the final stages of the life cycle (e.g. landfilling or recycling) and includes the transport of materials to the disposal/recycling facility. EOL may be positive or negative depending on the disposal mode. Examples of disposal modes include landfilling and combustion.

Energy recovery – refers to obtaining useful energy from wood waste through combustion.

Energy retained – refers to the total potential energy that could be produced from combustion of materials.

GHG substitution – refers to the amount of fossil fuel GHG emissions unreleased, when obtaining energy from wood instead of fossil fuel energy sources.

Initial embodied energy – refers to the embodied energy of a building once it has been completed, before any maintenance has been undertaken.

Maintenance (recurrent) related embodied energy – refers to the embodied energy of materials required to maintain the building.

Material reutilisation – refers to reusing certain building materials for other beneficial purposes, following deconstruction of the building. Examples include combustion of wood for energy or recycling of materials.

Operational energy – total primary energy consumed during the 60 year life of the building.

Primary energy – Energy required to produce a unit of useful energy (MJ or kWh), which includes all upstream processes. **Primary energy** is energy contained in raw fuels and any other forms of energy that has not been subjected to any conversion or transformation process. Primary energies are transformed in energy conversion processes to more convenient forms of energy, such as electrical energy and cleaner fuels.

Total embodied energy – refers to the sum of initial embodied energy, maintenance related embodied energy, operational energy, end-of-life energy, and energy recovered through material reutilisation.

Useful metered energy – Energy consumed at a point source, i.e. power socket.

1 Introduction

This report was produced for the Ministry of Agriculture and Forestry under the Request for Proposal POR/7811.

The 12-month collaborative research programme was directed by the Department of Civil and Natural Resources Engineering at the University of Canterbury, Christchurch.

Scion (Wellington) was sub-contracted to undertake a substantial part of the research work, namely the Life Cycle Assessment and Green Star rating tool analysis.

Acknowledgement of major contributions to the research programme is made to the University of Canterbury, Scion and Victoria University of Wellington. Important contributions were made by many others including engineering and energy consultants, architects, quantity surveyors and construction project managers.

All the Chapters in the report are written by the University of Canterbury, except Chapter 6, *Life Cycle Assessment* contributed by Scion.

The report is structured as follows;

Chapter 1 **Introduction**.

Chapter 2 **Executive Summary**.
A summary of the full programme of research, analyses, results, discussions and conclusions.

Chapter 3 **Background**.
Background information which positions the project and details goals and objectives and the Research Team. This section also provides general information about Multi-storey Timber Buildings and a significant combined NZ Government and industry commitment to fund future relevant research.

Chapter 4 **The Buildings**.
A key objective of the project was to design three buildings where the main structural components were either concrete, steel or timber. A fourth design, TimberPlus, maximising the use of timber throughout was also produced. All buildings have a projected 60 year lifetime.

Chapter 5 **Operational Energy**.
A key objective of the project was to ensure that the four buildings were 'low energy' and designed to consume very similar operational energy over the lifetimes of the buildings.

Chapter 6 **Life Cycle Assessment (LCA).**
Analysis and reporting by Scion. This chapter employs LCA to compare the environmental impacts of the four building designs, investigating the embodied energy of the various building materials and the building's lifetime recurring (maintenance and refurbishment) embodied energy and associated operational energy. Two end-of-life scenarios are presented. The Global Warming Potential (GWP) of each design is used to show differences between the buildings due to the different materials used. A high level comparison is presented between LCA and the NZ Green Building Council Green Star Office Design rating tool.
This chapter also includes the discussions and conclusions of Scion.

Chapter 7 **Building Construction**.
Construction schedules for the different building designs.

Chapter 8 **A Review of the Timber Used in the Timber Buildings**.
Investigation of the source, availability and certification of the timber assumed to be used in the buildings. Also, timber treatment, durability and the current situation in NZ for recycling and disposal of treated timber.

Chapter 9 **Discussion**.
This chapter presents discussions of many of the results and findings of this research. It includes an alternative end-of-life scenario to that proposed in Chapter 6.

Chapter 10 **Conclusions**.
Presented as a series of key questions and answers.

References.

The Appendices contain data and further information relevant to this report.

2 Executive Summary

The Research Goals and Objectives for this project were set out in the Ministry of Agriculture and Forestry (MAF) RFP POR/7811, April 2007. The University of Canterbury responded with a collaborative research programme '*to fill the information gap about what is the greatest amount of wood that can be used in the construction and fit-out of commercial, large-scale buildings in New Zealand (and) …… to provide Life Cycle Assessment (LCA) information about the benefits of maximising the use of wood in sustainable buildings'*.

This research project modelled the performance of four similar office building designs – Concrete, Steel, Timber and TimberPlus – all based on an actual six-storey 4,200m^2 building, to investigate the influence of construction materials on life cycle energy use and global warming potential (GWP).

All four buildings were designed for a 60 year lifetime, with very similar low operational energy consumption. The Concrete and Steel buildings employed conventional structural design and construction methods. The Timber buildings were designed with an innovative post-tensioned timber structure using laminated veneer lumber (LVL). The TimberPlus design further increased the use of timber in architectural features such as exterior cladding, windows and ceilings. All timber materials are renewable and durable, sourced from sustainably managed forests. Predicted construction times for all four buildings are similar.

The LCA study by *Scion* considered the full life cycle of the buildings including initial embodied energy of the materials, and maintenance, transport, operational energy and two end-of-life scenarios, where deconstructed materials were either landfilled or reutilised.

Increasing the amount of timber in the buildings decreased the initial embodied energy and GWP of materials and also decreased the total energy consumption and GWP over the 60 year lifetime. The TimberPlus design clearly had the lowest environmental impacts, whilst the Steel building had the highest impacts. A significant benefit could be obtained in the Steel, Concrete and Timber buildings by replacing high embodied energy components (especially aluminium windows and louvres) with timber.

The final destination of deconstruction waste at the end of the 60 year life-cycle is extremely important. Landfilling of timber waste, with the permanent storage of most of the carbon in the timber, was slightly more beneficial than burning of wood waste for energy. The benefits of landfilling timber waste will increase as modern and future landfill construction and management capture and utilise more of the methane generated by decomposition. Recycling of steel and concrete is more beneficial than landfilling.

It is important to note that looking at a single environmental indicator, such as GWP, could lead to unintended outcomes. For example, for the TimberPlus building the landfilling scenario would be slightly better in terms of climate change. However, looking at the energy results alongside the GWP results, the reutilisation scenario shows both an energy reutilisation benefit, as well as still being beneficial to climate change. Therefore, the use of multiple indicators may be necessary to inform the environmental decision-making processes.

An alternative end-of-life scenario which assumed permanent storage of carbon in wood materials showed that net total GWP for the materials in the TimberPlus building is negative, because the long-term storage of over 630 tonnes of carbon dioxide removed from the atmosphere more than cancels out all the greenhouse gases emitted in the manufacture of all the other building materials. In this scenario, the TimberPlus building could be considered to be ‘carbon-neutral’ for at least the first 12 years of its operation.

With NZ-specific energy and GWP coefficients now available, a simple model can be developed for assessing the energy and GWP impacts of individual buildings. This study shows that the Green Star Office rating tool does not capture all the benefits of using more wood in buildings which are identified by the simple model or a full LCA study.

Support of on-going research is essential to further develop the potential for Timber buildings to be more widely used in NZ, with subsequent reductions in greenhouse gas emissions.

3 Background

3.1 Research goals and objectives – MAF RFP POR/7811.

The broad Research Goals and Objectives for this project were set out in the Ministry of Agriculture and Forestry (MAF) Request for Proposal POR/7811 issued in April 2007. The University of Canterbury responded with a proposal (Operational Research Proposal Form – Part Two) which formulated a collaborative research programme bringing together a number of specialist and academic resources together with building industry consultants.

The Research Project proposed to design three comparable commercial buildings in Timber, Concrete and Steel and to conduct a full Life Cycle Assessment to determine environmental impacts associated with the buildings throughout their lifetime.

The research needed to achieve the following objectives (as identified by MAF);

- Fill the information gap about what is the greatest amount of wood that can be used in the construction and fit-out of commercial and large-scale residential buildings in New Zealand.

- Provide Life Cycle Assessment (LCA) information about the benefits of maximising the use of wood in sustainable buildings.

The research was supported by the rationale that;

- The Government has stated its wish to pursue policies that will move NZ towards being truly sustainable.

- Modern engineered wood products, recent advances in structural timber engineering and innovative designs now position timber as an alternative material (to concrete and steel) for multi-storey buildings.

- Wood is a renewable, low energy resource; there is a plentiful, sustainably-grown supply in NZ. Modern timber construction produces little waste and the manufacture of building materials from wood is generally non-polluting at all stages.

- Increased use of wood would provide national benefits over the long term (reduced fossil fuel energy consumption and CO_2 emissions; an increase in the pool of carbon in wood and wood products; and the potential for displacement of fossil fuel by burning of wood waste materials).

- To understand long-term sustainability, full LCA of building materials must be considered.

Over the past few decades there has been very little commercial and large-scale residential building utilising predominately wood and wood products. Whilst there is no technical or financial reason for this, a major barrier could be the conservatism of building owners and designers and a shortage of building design practitioners who are trained and experienced in the use of wood as a construction material for large buildings.

The information gap noted above is there because few have seen the need for this information until now, there are few examples and very few advocates.

Further impetus for this research was provided by the introduction of the New Zealand Green Building Council (NZGBC) Green Star Office rating tool (v1.0) which does not consider the full LCA of building materials; it does not consider embodied energy, nor give fair consideration to the displacement of more energy intensive building materials by wood, nor provide recognition of the ability to use wood waste to generate energy. Current research was needed to demonstrate the perceived shortcomings of the NZGBC rating tool and offer alternatives.

The initial research contract had three programme objectives:

Objective 1 To design three comparable buildings with the following structural materials; conventional reinforced concrete, conventional steel and innovative pre-stressed timber. MAF RFP POR/7811 provided methodology and design guides for the building.

Objective 2 To investigate both the embodied energy in the structural and non-structural materials and the whole-of-life operational energy of each building design, together with lifetime GWP emissions.

Objective 3 To demonstrate and highlight any differences between the total whole-of-life energy of each building, together with lifetime GWP emissions.

The research was extended in December 2007 to;

- Design a fourth structure, the TimberPlus building. This design was to go well beyond substituting the mainly structural components of the building to redesign the whole architecture, both internal and external. (For instance, the TimberPlus building maximises the use of wood through timber external cladding and internal partitions, and incorporates timber framed windows, doors and stairs). The TimberPlus option needed to maximise the use of wood but not beyond what would be a reasonable expectation both architecturally and aesthetically, whilst still offering a realistic maintenance schedule and within a similar budget to the Concrete and Steel options.
- Undertake additional work on the Steel building to allow the Steel building to be brought up to a more comparable level of design and research, similar to that for the Concrete and Timber options, and thus allow a more rigorous comparison of the four alternative designs.
- Extend the work on the schedule of materials for each building undertaken by the Quantity Surveyor to include the following categories; glass, aluminium, paint and finishes, particleboard/fibreboard and insulation.
- Undertake additional investigation by the Quantity Surveyor to provide a better understanding of where environmental impacts are greatest.
- Include the effects of building maintenance and refurbishment in the life cycle assessment.
- Expand the LCA work to include a sensitivity analysis on the environmental impacts of the transport distances of wood and other materials used in the buildings
- Expand the end-of-life aspect of the original LCA modelling work to investigate and report on the effects of landfilling of demolition waste and the possibilities for both the

recycling and use of demolition waste for the further displacement of fossil fuels – in the case of wood, by burning waste materials.

- Compare the New Zealand Green Star Office rating tool with LCA results to check for consistency, and make recommendations as to possible improvements to the Office rating tool.
- Engage an accredited Green Star consultant to provide a review of the comparison between LCA and Green Star.
- Determine and report on the type of timber used in construction and maintenance of the four building designs and the source of this timber, together with any applicable sustainable source certification.
- Broadly determine the amount and level of treatment of timber used in the construction and maintenance of the four building designs, with emphasis on the use of CCA treatments.
- Report on the current status for burning treated wood.

3.2 Research Team

The University of Canterbury (UC) was in a unique position to lead this research.

- UC is at the forefront of research into innovative design of large-scale, multi-storey commercial timber buildings.
- Existing research (from March 2007) at UC mirrored the proposed MAF-funded research.

The University of Canterbury provided overall project management and engaged a number of other research establishments and specialist consultants to provide expert information and advice.

In order to fulfil the Research Objectives, the research was organised in a number of distinct sub-programmes (with main contributors shown);

- Structural design of Timber, TimberPlus, Concrete and Steel buildings; UC and others.
- Architectural design of building; Victoria University of Wellington.
- Assessment of quantities of materials in each building by Quantity Surveyor, Davis Langdon Shipston Davies of Christchurch.
- Operational energy modelling and analysis of all four buildings; N. Perez, VUW.
- Life cycle assessment (LCA) of alternative building designs; Scion.
- Assessment and review of timber use in Timber buildings; Warren and Mahoney, Christchurch.

3.3 Government Policies Supporting Research

Listed below is a summary of the government directives around sustainable building practices. These directives have supported the growing interest (“push”) for more information, consideration and action on construction of commercial and large-scale timber buildings in New Zealand.

- Ministry for the Environment (MfE) lead.

  In May 2007, the NZ Government Cabinet directed public service departments to adopt a minimum five star Green Star New Zealand rating for the construction of all new and refurbished A Grade commercial office buildings and a minimum four star Green Star rating for B Grade commercial office buildings, as from 1 July 2007 [CAB Min (07) 18/7 refers].

  In May 2007, NZ Cabinet directed public service departments to adopt the Ministry for the Environment Commissioning Guidelines for all new government owned or leased buildings over $2000m^2$ from 1 July 2007. Ministry for the Environment website: http://www.mfe.govt.nz/publications/sus-dev/sustainable-government-buildings-jun07/.

  In September 2007 the NZ Government set a target that all new government buildings meet a minimum five star Green Star New Zealand rating from 2012 [CBC Min (07) 21/16 refers]. New Zealand Energy Efficiency and Conservation Strategy 2007, page 76. http://www.eeca.govt.nz/eeca-library/eeca-reports/neecs/report/nzeecs-07.pdf

- Ministry of Economic Development lead.

  Public Service departments are required to ensure that the final disposal of construction and demolition timber is in line with the waste minimisation principles set out in the Resource and Efficiency in Building and Related Industries (REBRI) guidelines. When entering into building or construction contracts that include the use of timber and wood products, ensure prime contractors and sub-contractors apply the REBRI guidelines to the building project (eg, develop a site waste management plan and separate materials for recycling).
  http://www.med.govt.nz/upload/51276/category-reviews.pdf

  Public Service departments are required to ensure that wood products purchased are made from timber that is legally sourced and take all reasonable steps to ensure that this timber originates from sustainably-managed sources, in accordance with the New Zealand Timber, Wood Products and Paper Procurement Policy.
  http://www.med.govt.nz/upload/51276/category-reviews.pdf

- Ministry of Agriculture and Forestry lead.

  Until recently, there was also a requirement to have a build in wood design option for government commercial buildings up to, and including, four floors. More information is available on the Ministry of Agriculture and Forestry website: www.maf.govt.nz

3.4 Multi-Storey Timber Buildings

3.4.1 Introduction

Timber construction is ideally suited to multi-storey buildings because of its high strength-to-weight ratio. For areas where seismic design will govern or where foundation issues exist, the light weight nature of a predominantly timber building means much lower earthquake loads and lower foundation loads than for a reinforced concrete building, which can lead to a very economical design.

3.4.2 Forms of Multi-Storey Construction

The main categories of use are residential and commercial.

Multi-storey residential buildings are characterised by a large number of separate rooms on each floor, a large number of permanent walls, and relatively short-span floors supported on walls. These buildings are usually light timber framing, although cross-laminated-timber is starting to become popular in Europe. The large number of walls is useful for lateral load resistance. Some of these are likely to be inter-tenancy walls with special requirements for acoustic properties and fire resistance. Most of the timber structure will be hidden from view, protected by gypsum plasterboard.

Multi-storey commercial buildings are characterised by a large open spaces, with very few walls, and relatively long-span floors supported on beams and columns. The only permanent walls may be those at the perimeter and around the lift shaft and stairwells. Timber beams and columns may be visible timber elements in the finished building.

3.4.3 Typical Structure

Typical structural form for multi-storey residential buildings consists of the following elements:

- The roof is supported on timber purlins, timber rafters and timber roof trusses.
- The floor is wood-based panel on timber joists, either solid joists or proprietary engineered joists. Alternatively, the floor may be a manufactured system utilising joists and plywood in stressed-skin panels, or timber-concrete composite floors.
- The floors are supported on light timber frame walls, or timber beams.
- The beams are supported on timber columns or walls.
- Walls usually consist of light timber framing clad with plywood sheathing or gypsum plasterboard lining.
- Other wall options are solid LVL walls or other timber products, such as *Triboard* or cross-laminated-timber.

3.4.4 Material selection for multi-storey timber buildings

The Journal *Structural Engineering International* (2008) provided the following introduction to an edition dedicated to *Tall Timber Buildings*;

> Timber has been a preferred construction material since the dawn of civilisation due to its natural abundance, high ratios of stiffness and strength to weight, and the ease with

> which it can be fashioned to shape. Over about the last decade, governmentally imposed prescriptive regulations that define how buildings have to be designed and constructed have begun to be replaced by performance based codes. New and evolving regulations directly address performance attributes of alternative combinations of materials, construction methods and building geometry. This proves especially liberating for designs employing timber because engineers are given the freedom to apply and derive benefits from advanced design technologies and to use modern timber construction products. In Britain, Italy and Switzerland, for example, six storey or taller timber buildings are now accepted. In North America, four storeys is usual with occasionally five or six storeys allowed by authorities with local jurisdiction. With the correct choice of building methods, 20 storey or taller timber buildings are technically possible. Ten storey timber buildings becoming quite common is a practical near term goal. Researchers at various institutions in Europe, North America and Asia are performing large scale tests and developing design concepts and methods necessary for that to become a reality.

There is a wide range of structural systems available for multi-storey timber buildings. Most of these are in one of the following categories:

- Historical timber buildings
- Traditional heavy timber frame construction
- Light timber frame construction
- Cross laminated timber (CLT)
- Post-tensioned timber frames and walls

3.4.4.1 Historical Timber Buildings

Timber has been used for many centuries for construction of traditional historical timber buildings including multi-storey pagodas in Asia, stave churches in Scandinavia, and combined timber and masonry building in many European cities.

3.4.4.2 Traditional Heavy Timber Frames

"Traditional heavy timber frame construction" describes buildings of large dimension beams and columns connected together by timber or steel dowels, or steel or plywood gusset plates for moment resistance. Such forms of construction are common in both historical and modern timber buildings, especially in North America. The timber beams and columns may be Glulam, sawn timber, or rough members hewn from logs.

3.4.4.3 Light Timber Frame

"Light timber frame construction" is the most common form of multi-storey timber buildings, using small section sawn timber as wall studs and floor joists. Stud and joist sizes are typically from 90x40mm up to 250x50mm or more. This construction is very popular in North America where it is often called "wood frame construction" or "two-by-four construction". Flooring and structural walls are usually clad with plywood or particle board. Internal walls are lined with gypsum plasterboard. Wall and floor cavities are often filled with light weight insulating materials for thermal and acoustic performance.

3.4.4.4 Cross Laminated Timber

Cross laminated timber (CLT) panels are rapidly becoming popular in Europe for prefabricated multi-storey timber buildings. CLT panels are large timber panels of solid wood, manufactured from layers of sawn timber boards in alternating directions (similar to thick plywood). The boards are glued or nailed or dowelled together to construct the panels.

The boards are usually about 90x20mm size, in panels which may be from five layers thick up to ten layers thick (100-200mm panel thickness). The panels can be used for all the walls and floors of large buildings. Room sizes are small because all the walls are structural walls and floor spans are limited.

3.4.4.5 Post-tensioned Timber Frames and Walls

A new form of multi-storey timber construction being developed in New Zealand, based on recent developments in reinforced concrete construction for seismic areas, uses post-tensioned timber frames and walls. For further information see Section 4.4, Multi-storey Timber Building Research.

3.4.5 Height Limits for Multi-Storey Construction

Height limits considering the gravity load resisting structure are as follows (see the Timber Design Guide, Buchanan, A., 2008):

- The upper limit for light timber framing for gravity structures is in the order of 5 to 8 storeys, depending on the configuration of the building.
- The upper limit for LVL post and beam gravity systems could be in the order of 15 to 25 storeys, depending on the configuration of the building.
- The economically competitive span limit of timber floor construction utilising engineered wood products is likely to be around 8 or 9 metres. Typically, spans of around 6 metres are generally the maximum used in practice with engineered wood products and other systems available at present.

Height limits considering the lateral load resisting structure are as follows:

- The upper limit for plywood shear walls is in the order of 5 to 8 storeys, depending on the configuration of the building.
- The upper limit for solid LVL shear walls is untested and is the subject of research at present, however they would be expected to exceed the capacity of plywood shear walls by a considerable margin.
- The upper limit for timber moment resisting frames is likely to be in the order of 5 to 10 storeys, depending on the configuration of the building.
- The upper limit for plywood floor diaphragms will be driven by the capacity of nailed connections from the plywood to the framing. The loads imposed by seismic floor accelerations are likely to exceed nail capacities at about 15 to 25 storeys, depending on building configuration. Site glued connections would allow the possibility of higher buildings however the issue of glue durability and the suitability for site application may render a structural site glued option impractical.
- The upper limit for using gypsum plasterboard bracing systems is likely to be around 4 storeys, depending on the configuration of the building.

Hybrid structures are possible *w*ith a combination of **timber** *gravity load resisting structure* and **steel and/or concrete** *lateral load resisting structure.* With this combination of materials, a predominantly timber building could be designed and constructed which would be limited in height only by the capacity of the timber gravity load resisting system and the floor diaphragm system, i.e. 15 to 25 storeys.

For fire safety, the New Zealand Building Code does not limit the height of timber buildings. With proper attention to design and detailing, timber buildings can be as safe as buildings of other materials, so fire safety will not limit the possible height.

3.4.6 References

For further information, refer to the following publications:

Multi-Storey Timber Buildings Manual, by Graeme Beattie, BRANZ. Published by CHH, FCF, JHBP, & WWB. 2001.

Multi-Storey Timber Frame Buildings; a Design Guide, by R. Grantham and V. Enjily. BRE/TRADA, UK.

Feasibility of Low-Rise Timber Commercial Buildings. Research Report 91-3, Department of Civil Engineering, University of Canterbury. 1991.

The Seismic Design and Behaviour of Multi-storey Plywood Sheathed Timber Framed Shearwalls. Ph.D. Thesis, University of Canterbury. 1996.

The Timber Design Guide. Third Edition 2008. Edited by Professor A. Buchanan, University of Canterbury. New Zealand Timber Industry Federation Inc.

3.5 Structural Timber Innovation Company

3.5.1 New Research Consortium

This research document is based on the design of innovative, multi-storey Timber buildings The development of these buildings from the under-pinning engineering, through to design, enhanced timber technology, fabrication and construction is already being researched. However, with the recent approval for the funding of a multi-million-dollar Research Consortium - being co-funded by the NZ Government and industry for an initial period of five years - a new level of research and market-driven commercialisation commenced in August 2008 with the formation of the Structural Timber Innovation Company Ltd. (STIC).

The largest investor in STIC is the NZ Government, through the Foundation for Research Science and Technology (FRST), providing 1:1 matching funding with industry. The founding shareholders are Carter Holt Harvey, Nelson Pine Industries, Wesbeam (Australia), NZ Pine Manufacturer’s Association, Building Research of NZ, University of Auckland and the University of Canterbury. In addition, Forest and Wood Products (Australia) is a major contributor under a Service Agreement.

The company is overseen by a Board of Directors, and managed by a CEO. The research is directed by Professor Andy Buchanan from the University of Canterbury. A Commercialisation Committee of shareholder representatives drives market acceptance and commercialisation of the research findings.

The company has major research contracts with the University of Auckland, the University of Canterbury, University of Technology, Sydney and BRANZ Ltd. It also collaborates with the

University of Sassari and the Technical University of Milan, in Italy, and other overseas universities and research establishments as appropriate.

3.5.2 Vision

The central focussing question which has driven the formation of STIC is;

How can New Zealand create new markets both nationally and internationally for innovative timber building systems, which will allow cost-effective construction of attractive, flexible and durable buildings, with reduced construction time and much lower environmental impacts than traditional construction ?

STIC is driving the development of innovative large-span timber buildings for a wide range of uses in New Zealand, Australia and other export markets. Primary applications include commercial, educational, industrial, recreational and residential buildings.

These buildings will have their main structural members manufactured from high quality engineered timber components including Glulam and LVL (laminated veneer lumber). The buildings will be from single storey to six storeys or more.

Compared with buildings from traditional materials, these new buildings will be:
- More attractive and more desirable places to live and work.
- Lower in weight, with easier transportation of components and less expensive foundations.
- Less expensive to construct through good design and extensive prefabrication.
- Easier to heat and cool with better acoustic performance.
- More resistant to major earthquakes and extreme weather events.
- Safer in fire and other emergencies.
- Less energy-intensive in the manufacture of materials and life-time use, resulting in lower CO_2 emissions, helping to meet government’s objectives of carbon neutrality.
- Less wasteful of materials, with lower environmental emissions during construction and re-use.

3.5.3 STIC Objectives

The Structural Timber Innovation Company (STIC) has created a step change in New Zealand’s wood manufacturing and construction industries. It is enhancing the international competitiveness of the wood manufacturing sector and developing innovative solutions for construction of timber buildings world-wide.

STIC targets sustainable construction, developing new building solutions which greatly reduce environmental impacts. It is developing a wide range of new, high-value structural products, and is adding value to lower grade wood products that are part of the total construction package.

STIC is developing, commercialising and facilitating new structural timber solutions for New Zealand and Australia followed by the United States and other export markets. Development has started with large-span, single-storey buildings, moving on to two to six storey open plan buildings for low seismic areas, then similar or taller buildings for high seismic or high wind areas.

STIC is producing comprehensive design guides for designers, regulators, manufacturers and builders. Delivery of the new building systems is supported by strong relationships with fabricators and construction companies in local and international markets. Buildings are constructed from prefabricated components, including beams, columns, frames, floors, walls, partitions and cladding panels, manufactured from sawn timber, glue laminated timber (Glulam), laminated veneer lumber (LVL), and wood-based panel products.

3.5.4 Scope of Research and Development

The scope of the STIC project is very large. Some of the major points are:

- The new form of building construction uses large prefabricated timber building elements in arrangements only previously built with concrete or steel.
- This is leading to an innovative change in the New Zealand construction industry, which is traditionally a cautious and conservative industry.
- Large scale prefabricated and post-tensioned timber construction mirror recent developments in reinforced concrete construction.
- The new construction is possible because Glulam (glued laminated timber) and LVL (laminated veneer lumber) have changed radiata pine from a commodity to an engineering material.
- Design guides, software and other support tools are an essential part of the programme.
- A provisional patent has been sought for several aspects of this new construction system.
- Overseas help will be needed to develop export markets.
- This new form of construction provides a sustainable building option which will make a major contribution to meeting the New Zealand government's objective of carbon neutrality.
- A wide range of topics is being addressed, including structural engineering, architecture, sustainability, construction and cost, fire safety, acoustic performance, and durability.
- The modular system concept for large prefabricated timber buildings will result in a new timber fabrication industry, manufacturing new building products for domestic and export markets.

Figure 3.1 Medium term goal - multi-storey commercial and residential buildings

3.5.5 Market Drivers

The market drivers pushing development of the new buildings include:

1. Strong international demand for low to medium-rise residential and commercial buildings as a result of demographic changes.
2. Demand for sustainable buildings, renewable materials and reduced CO_2 emissions.
3. Stated government objectives for carbon neutrality in the building industry and wider economy.
4. Industry demand for prefabrication and integrated construction of long-span buildings.
5. Increasing importance of rapid reparability and re-use after extreme seismic and weather events.

3.5.6 Objectives

The following is a summary of the research objectives to be carried out by STIC;

Objective 1 - Single storey timber roofs and portal frames – 30-40m span.

- New long span roof and portal frame systems.
- Design of fasteners for large static and dynamic loads.
- Connections – develop new portal frame knee joints.

Objective 2 – Timber floors for multi-storey timber buildings.

- Floor systems and construction.
- Structural performance of floors.
- Fire resistance.
- Acoustic and vibration performance.
- Long term performance.

Objective 3 - Multi-storey pre-stressed timber walls and frames.

- Structural form and construction.
- Structural frames to resist gravity loads.
- Fire resistance.
- Long term performance.
- Structural frames and walls for seismic loads and extreme wind loads.
- Energy use and sustainability.

4 The Buildings

4.1 Construction Materials for Commercial Buildings

Most commercial buildings tend to make extensive use of steel, glass, and concrete materials in construction, all of which can be energy-intensive to produce, via processes that have the potential to cause adverse environmental impacts and utilising resources that are in shortening supply.

However, recent developments in wood technology and engineered timber products, seismic and acoustic design, fabrication and construction techniques have enabled timber to be utilised much more extensively for the basic structure of medium-rise, multi-storey buildings, such as a typical 'down-town' office block.

While there is a tendency for commercial buildings to be labelled according to the main material used for their sub-structure and super-structure, the vast majority of buildings use a large number of different materials, from a variety of sources, both national and international. From a materials perspective, a building becomes a very complex system and it is often not immediately clear which materials or combinations of materials provide the best environmental performance (in terms of life–cycle energy use and GWP, for example). While conscious of these limitations, this report will retain this labelling system as it is current practice.

Studies have indicated that typically **structural** components account for between 16 and 65 per cent of initial embodied energy (Aye, Bamford, Charters, & Robinson, 1999; Cole & Kernan, 1996; Oppenheim & Treloar, 1995; Treloar, Fay, Ilozor, & Love, 2001). Hence, when considering the environmental impacts of building materials, the structural components used in a building are of significant importance.

This report emphasises alternative structural design options where the predominant structural material is either concrete, steel or timber.

4.2 Building Design

There are two main aspects in the design of a multi-storey building. The *structural* design considers all the main structural components - the *skeleton* - including the foundation, the beams, columns, external walls, as well as the internal flooring system and roof structure. The *architectural* design provides the external cladding including windows and louvres, internal walls, insulation, etc.. In some areas, the distinction between structural and architectural design is not clear cut and there can be considerable overlap; changes to the structure often enforce changes to the architecture and visa versa meaning any final design is therefore the result of an iterative, developmental design process.

The design of the four case study buildings covered by this report was the combined output of structural engineers and architects, working together.

The case study buildings analysed in this research are based on an actual building, a new six-storey, 4,247 m^2 (gross floor area) (3,536 m^2 net usable area), science laboratory for the

School of Biological Sciences at the University of Canterbury in Christchurch. It was designed by local Christchurch architects (Courtney Architects) and structural engineers (Cusiel Lovell-Smith) with conventional pre-cast reinforced concrete as the main material for the structure, envelope walls, floors and roof slabs. This building - currently under construction – will be linked by an atrium to the present Zoology building at the University.

Figure 4.1: Perspective view of the new Biological Sciences laboratory at the School of Biological Sciences, University of Canterbury.

4.3 General Design Concepts

The above building design was modified to provide a simplified template for the development of the four alternative case study buildings covered by this report.

Each case study was designed as a stand-alone building, keeping the same original orientation but removed from the adjoining Zoology building and redesigned internally as a commercial office building. All new case studies are based on the same simplified template as that of the original laboratory building, as shown in Figure 4.2, where the stand-alone laboratory building in plan view (left hand) is compared with the concrete case study building (right hand) used in this research. The part of the atrium which contains the stairs, lift, bathrooms and corridors remains attached to the simplified template building. The six storey building is approximately 36 metres by 20 metres in plan with one stair and one elevator

All four buildings are designed as the same simple commercial (office type) building with open plan floor spaces rather than the complex laboratory layout of the actual building but retain the ‘plant / riser ducts’ (two enclosed void areas closed to the south façade). Each duct is approximately eight meters by four meters and the length of these is placed transversally to the building. The basement level of the structure present in the original laboratory design was removed for the new design and therefore the foundation level was altered to accommodate this change

The building structure has been designed for the Christchurch region, in what can be considered to be a moderate seismic zone. The foundations are in reasonably good conditions, considered to be a shallow soil. For all structural design, the current New Zealand design codes have been used. Where these have not been adequate, particularly in the case of the timber buildings, other relevant international codes have been utilised.

The structure has two distinct seismic systems in order to resist loading in the north-south and east-west directions. In the long (E-W) direction, a moment resisting frame is used; in the short (N-S) direction, walls are used.

4.3.1 Four Alternative Buildings – Description

The template building was used to produce architectural and structural drawings for four alternative case studies in which the structures and finishes are predominantly either concrete or steel or timber.

The four case study buildings were designated:

Concrete building – pre-cast reinforced concrete exposed in structural frames and shear walls, with the same external fibre-cement cladding as the actual Biological Sciences building in the light weight walls in South façade..

Steel building – all the main structural components are steel, with the use of Eccentrically Braced Frames (EBF) resisting lateral loading in both (short and long) directions. Framing and cladding are steel.

Timber building – the main structural components are prefabricated laminated veneer lumber (LVL[1]) columns and beams, the east and west walls are prefabricated solid LVL

[1] Structural Laminated Veneer Lumber (LVL) manufactured to AS/NZS 4357.0 Structural Laminated Veneer Lumber is an assembly of veneers laminated with a Type A phenolic resin. The grain direction of the outer veneers and of most or all of the inner veneers is in the longitudinal direction. LVL is suitable for use in all permanent structural applications and it has a wide variety of uses including beams and columns, truss chords, I-beam flanges, scaffold planks, concrete formwork supports and supports for structural decking.

Although the Type A bond is durable and permanent under conditions of full weather exposure, long term stress, and combinations of exposure and stress, the timber species may not be durable when used in weather exposed situations. In exposed applications, structural LVL must be preservative treated to ensure it lasts its full service life and surface finished to minimise surface checking.

The design properties of structural LVL as well as product dimensions are published by the individual manufacturers. LVL dimensions vary between manufacturers, however manufactured billets are nominally 1200 mm wide and in standard thicknesses of 35 or 36, 39, 45, and 63 mm. Other thicknesses are available from some manufacturers. The 1200 mm wide billet is ripped into standard beam depths and includes beam depths of 1200 mm deep.

The veneer grades for LVL are controlled by the manufacturing specification of each individual LVL manufacturer.

LVL is manufactured under a rigorous product quality control and product certification scheme. This ensures an engineered product of known and consistent physical and mechanical properties.

members, floors are timber / concrete composite and the external cladding is fibre-cement.

TimberPlus building – as for the Timber building above but with greatly increased use of timber throughout including timber external cladding and cedar windows and louvres, solid timber internal walls, timber ceilings and other features which maximise the use of timber throughout the building.

- The Concrete building design is very similar to that provided by Courtney Architects.
- The preliminary Steel building design was provided by Steel Construction New Zealand Limited and modified by structural engineers from Holmes Construction and the University of Canterbury, with architectural design by Victoria University of Wellington (VUW).
- The Timber and TimberPlus designs were produced by engineers at the University of Canterbury, with architectural design by Victoria University of Wellington (VUW).

In each design, the objective was to use as much of the target material as *reasonably possible,* both in structures and finishes. However, to standardise - and adhere to "*good NZ design practice*"- for the Concrete, Steel and Timber designs, many interior and exterior finishes are as commonly found in typical NZ multi-storey buildings and similar in each design. For example, windows, curtain walls in the north and south façade, sun louvres in the north façade, roof cladding and internal finishes such as most of the linings and ceilings are the same.

The TimberPlus building was designed so that all possible '*common finishes'* of the Timber building were replaced by timber components.

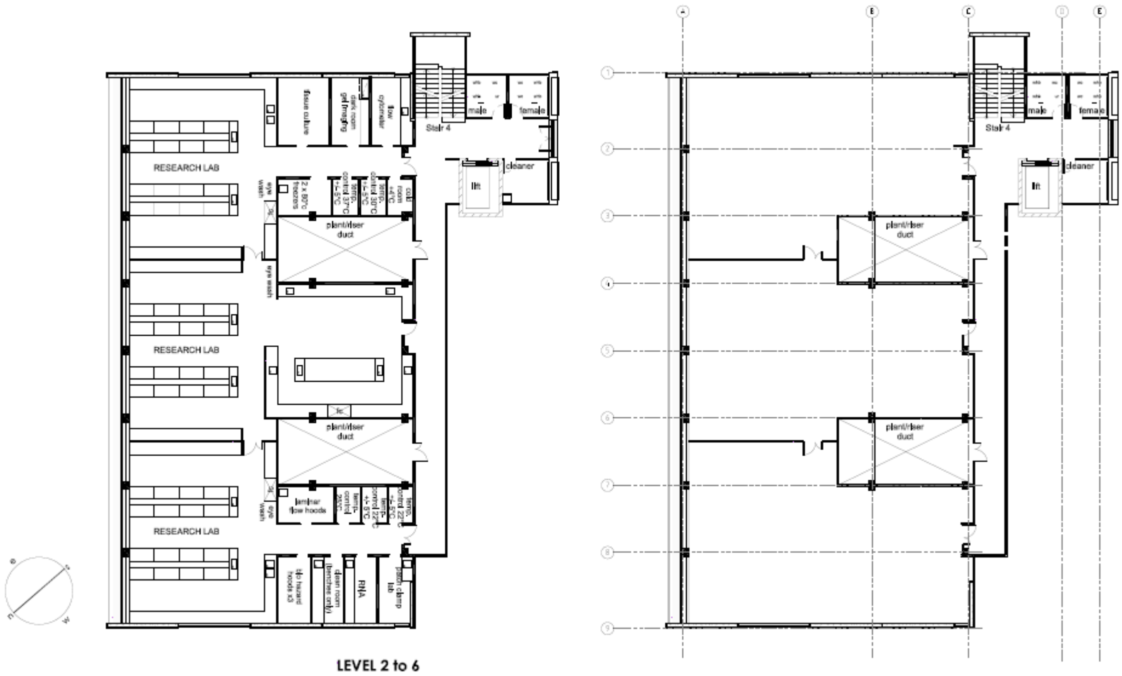

Figure 4.2: Plan of the simplified layout used in the concrete, steel, timber and TimberPlus buildings.

4.3.2 Common Design Principles

Many design features are common to the Concrete, Steel and Timber buildings and these are described below. Indeed, many design features are also common to the TimberPlus building; however, there are also important differences to note, particularly in the architecture. Where the TimberPlus building has notable differences, these will be described.

In all four case studies the building's envelope walls are the same at the east and west ends and different on the north and south faces. For the Concrete, Steel and Timber buildings, the north facade construction is the same with a curtain wall made of double glass windows framed in aluminium mullions and transoms. The aluminium louvres outside the curtain wall cover all the façade from the first floor up to the roof ‘soffit’. (The ground floor has glazed walls and doors as a commercial building, see figure 4.4).

For all case studies, the east and west façades are solid walls (but different materials) with only two narrow windows, one vertical (south corner) and one horizontal window centred in the façade. The south side of the building has an external corridor that connects the offices with the stairs, lift and toilets service area (see figures 4.2 and 4.5). Corridors are enclosed between a light wall (south façade of internal offices) and a single glass aluminium framed curtain wall (south facade of building) (the TimberPlus building has cedar window frames). The south façade curtain wall is the same for the Concrete, Steel and Timber buildings.

The foundation level of the original building was altered from the original design of the concrete structure, removing the basement, meaning that a re-design of the original foundation level was required.

It was assumed for design purposes that the building is situated on a moderately strong soil. For the Timber building, beam foundations are placed under both the seismic frame and walls, with pad foundations under the four central gravity columns (Figure 4.3). This layout was also used for the Concrete building; however a slight increase in the capacity of the foundations was necessary. For costing analysis, the foundations for the Steel building were considered to be the similar to that of the Timber building due to the similar masses of the structures. However, after consultation with Holmes Consulting Ltd a 15% increase was added due to the considerable uplift forces applied by the eccentrically braced frames.

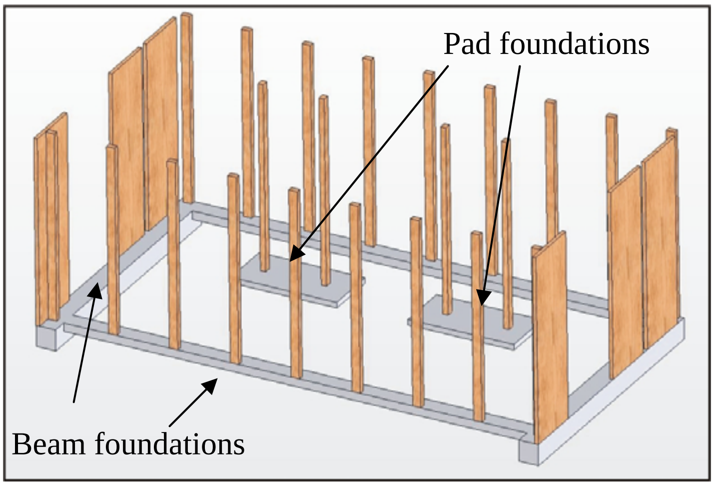

Figure 4.3: Foundation layout for timber building

Calculations of the foundation size for the Timber and Concrete building showed that the size of the foundations required is comparable. This is unexpected due to the lightness of the Timber building intuitively leading to a reduction in foundation size. However, the foundation size was principally governed by the overturning moment applied by vertical members during a seismic event, and not gravity loading. It can be expected that a significant reduction in foundations between the Timber and Concrete structures will occur if a building is gravity dominated or is situated in soft soil.

Figure 4.4: North-east façades perspective view of the simplified Concrete building, north façade.

The north-east perspective view of the Concrete building in Figure 4.4, is also representative of the Steel, Timber and TimberPlus buildings. The overall architectural design is the same in all four buildings but built in different materials and using different building techniques.

In Figure 4.4, it is possible to identify the layout of the north face curtain wall behind the parallel louvres. The seven structural columns from floor to roof slab are visible. The east face wall is the same as the west face wall and it is possible to see the stair well coming out of the service area in the south end of the east face wall.

The stepped shape of the roof is due to the plant room which increases the roof height on the south side of the roof. Inside the plant room, chimneys exhaust the air from the offices when these are being naturally ventilated. The roof-top plant room in the Concrete, Steel and Timber case studies is designed to have a combination of profiled metal cladding and aluminium opening louvres to the walls. Offices have opening vents which will allow heat to be purged into the chimneys when not required and from these to the plant room where opening louvres will exhaust the air to the exterior of the building. The TimberPlus building replaces the metal cladding and aluminium louvres with cedar timber components.

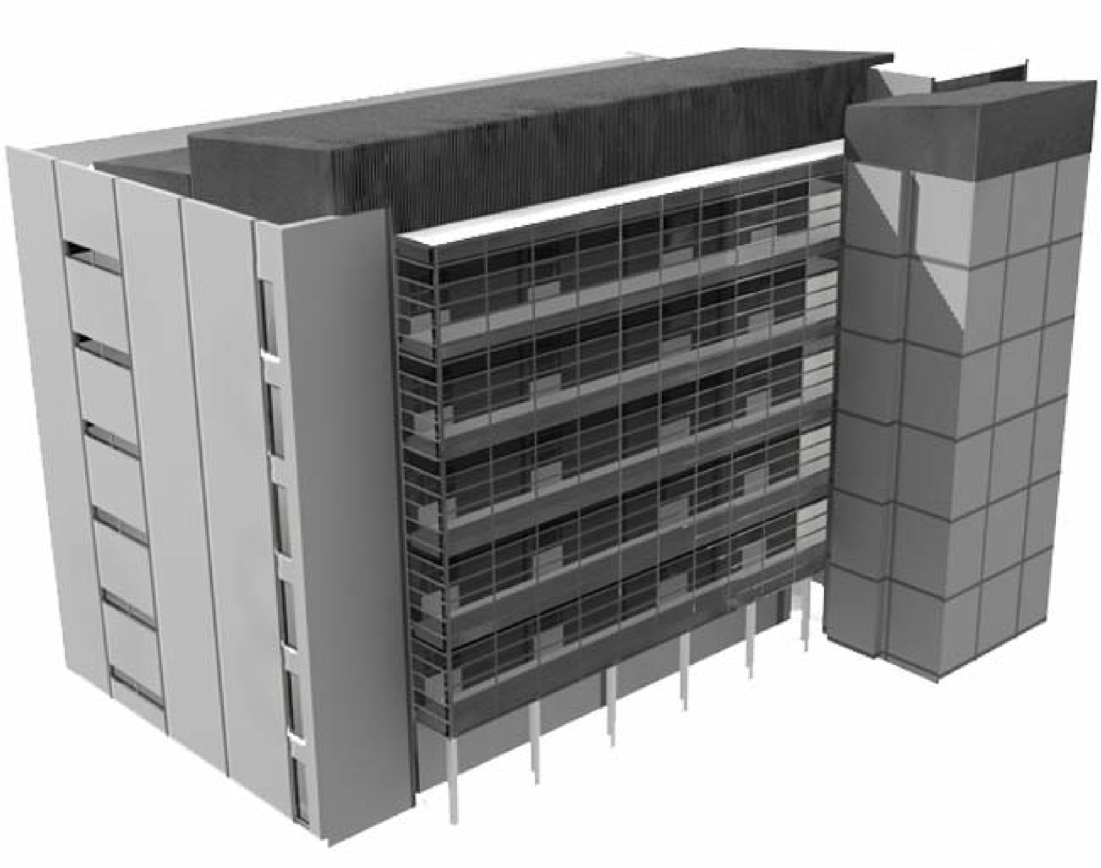

Figure 4.5: South-west façades perspective view of the simplified Concrete building.

Figure 4.5, the south-west perspective of the Concrete building, shows the corridors through the south face single glass curtain wall. These connect the service areas in the east end with each of the three internal offices areas. The service area envelope wall is reinforced concrete with steel sheets profiles as roof cladding. The west face envelope wall returns into the south face and runs inside the corridors enclosing the office areas.

The following descriptions are an overview of each alternative building design. Note that the overall structure has been maintained in all four case studies but some changes were necessary as noted.

4.3.3 Concrete Building

4.3.3.1 Structural System

The Concrete building is a conventional pre-cast reinforced concrete column, beam and wall structure. The building is raised floor-by-floor with concrete shear walls at each end of the building. Rectangular columns and beams form a frame on the north and south faces. Internal beams are supported on one internal row of columns spanning approximately 12 metres to the north edge and 6 metres to the south edge. These support the long span pre-cast floor units.

4.3.3.2 Floors and Roof

The floors are pre-cast 'hollowcore' floor slabs supported by the frame beams. The thickness of the hollowcore slabs ranges from 200-30 mm with a 75 mm reinforced concrete topping. Two openings for the vertical chimneys are left in all floors. The roof is formed using the same pre-cast units as the upper floors complete with topping system. Over this structure, a lightweight timber and steel framed roof is built with metal roofing. The plant room roof is constructed in timber and steel frame and is clad in the same material as the main roof.

4.3.3.3 Structural Walls

The east wall, west wall and part of the south façade are a 310 mm thick "*Thermomass*" wall; a composite wall with 60 mm concrete on the exterior, 50 mm of extruded polyurethane insulation in the core, and 200 mm of exposed reinforced concrete to the interior of the building. The service area walls are 200 mm reinforced concrete walls.

4.3.3.4 Internal Partitions

The light weight walls on the south face of the offices and the walls to the ventilation chimneys are timber framed containing 90 mm thick fibreglass insulation and a 25 mm air cavity for the exterior walls. Internally, the timber framed walls are lined with gypsum plasterboard. Acoustic insulation is required between partitions of the main body of offices. Generally, a plaster acoustic tiled ceiling is used in all office areas. The solid concrete exposed walls have a clear sealer applied; plasterboard walls have paint finish and all pre-cast concrete walls have an external finish.

4.3.4 Steel Building

Figure 4.6 shows the north-east and south-west perspective views of the Steel building.

The structure of the Steel building consists of a concrete foundation supporting steel beams and columns. Both internal and external walls are non-structural elements, being light weight steel stud walls supported between floors. This is the only design in which the east and west end envelope walls are not part of the structural system.

Figure 4.6: Steel building, north-east and south-west perspective views.

Both curtain walls in the north and south façade are the same as in the Concrete and Timber buildings.

4.3.4.1 Structural System

The Steel building is a column and beam steel structure braced by eccentrically braced frames (EBF). Figure 4.7 (one of the drawings provided by Steel Construction New Zealand (Xiao & Fussell, pers. comm.)) sketches the proposed layout of the recommended steel structure for the simplified Steel building. There are three frames of columns and beams running along the building, one at each long edge and one internal frame. Transverse secondary beams connect the three longitudinal frames. The floors are braced by Eccentrically Braced Frames (EBF). There are two frames in the longitudinal direction located at the perimeter of the building. There are four frames in the transverse direction inside the building, located beside the chimney voids.

Figure 4.7: Sketches of the layout of Steel building structure (right) compared with the layout of the actual laboratory concrete structure (left).

4.3.4.2 Floor and Roof

The floors and roof slab use the *Comfloor* system, where a 0.9 mm corrugated galvanized steel sheet supported by the structural beams, is topped by 150 mm of reinforced concrete with a total floor depth (floor plus beam) of typically 610 mm. The roof slab is formed using the same *Comflor* system complete with concrete topping and a 75 mm thick fibreglass insulation layer below the steel deck. Over this structure a steel framed roof is built with metal roofing. The roof plant room is constructed in steel frame and is clad in the same material as the roof (Xiao & Fussell, pers. comm.)

4.3.4.3 Structural Walls

The envelope walls at each end of the building and around the service shaft have been assumed to be non-structural elements. Walls on the east and south faces are supported between floors slabs, so that the heavy steel structure is exposed inside the building, and hence not able to act as a thermal bridge. The envelope walls in the east, west and south facades (enclosing the main body of offices) are framed in lightweight cold rolled galvanized steel studs and contain 90 mm fibreglass insulation. These have a 30 mm air cavity for ventilation and the cladding is painted steel sheet profile.

4.3.4.4 Internal Partitions

Internal partitions are framed in lightweight galvanized steel studs with gypsum board lining materials, and they contain 90 mm fibreglass insulation. Acoustic insulation is required between partitions of the main body of offices. Generally, a plaster acoustic tiled ceiling is used in all office areas and all plasterboard is painted.

The integrity of the steel building design has been carefully checked and scrutinized by professional engineers at Holmes Consulting Group in Christchurch. A letter, included in Appendix F, summarises the design and recommends that the foundation structures be increased in mass by 15% but otherwise confirms that the design is structurally sound and acceptable within normal NZ design standards for steel multi-storey buildings.

4.3.5 Timber and TimberPlus Buildings

4.3.5.1 Structural System

The Timber and TimberPlus buildings are constructed from a new post tensioned structural timber system being developed at the University of Canterbury (Buchanan, Deam, Fragiacomo, Pampanin, & Palermo, 2008; Paleremo, Pampanin, Fragiacomo, Buchanan, & Deam, 2006; Smith, Pampanin, Fragiacomo, & Buchanan, 2008).

The structural timber columns, beams and shear walls are prefabricated from laminated veneer lumber (LVL) and assembled on site with post-tensioned connections. The beams, columns and walls are fabricated from multiple layers of 63 mm LVL glued together into large prefabricated components. Most beams and columns are approximately 400 X 600 mm in cross section.

Earthquake and wind resistance are provided by moment-resisting frames in the longitudinal direction and cantilever shear walls in the transverse direction. The moment-resisting frames have post-tensioned beams supported between continuous solid timber columns which are not post-tensioned. The cantilever shear walls have vertical post-tensioning tendons and some yielding steel bars as energy dissipaters at the base.

Figure 4.8 shows a structural slice through one floor of the Timber and TimberPlus building (both being the same). The columns in the north and south frames and in the centre row can be clearly seen. The centre columns sit on the long edges of the voids. Structural shear walls are visible in the east and west faces and also the module of the prefabricated floor system. Light-weight timber framed walls are placed between the structural shear walls. All the columns are located in the same position and have similar sizes to the columns in the Concrete building.

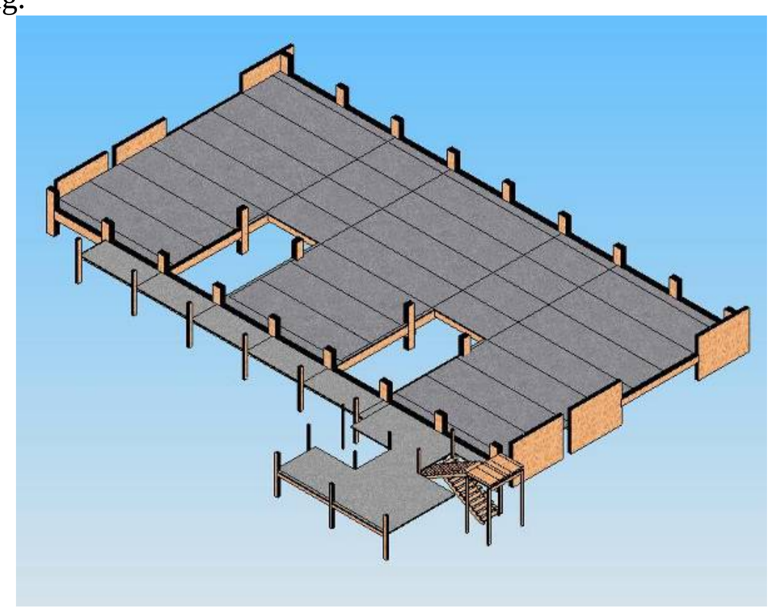

Figure 4.8: Structural slice through one floor of the timber and TimberPlus building.

4.3.5.2 Floor and Roof

The structural system which supports the flooring has been altered slightly from that of the Concrete building, in order to reduce the maximum span from 12 metres to 9 metres, as shown in Figure 4.8. The upper floors and the roof slabs are timber-concrete composite slabs built using prefabricated structural LVL and plywood decking supported on four internal structural timber (LVL) gravity beams and the end walls. The plywood decking supports a 60 mm thick reinforced concrete composite topping, fixed to the LVL joists by notches and embedded coach screws. The roof slab contains a 75 mm thick fibreglass layer.

4.3.5.3 Envelope Walls

The solid, structural LVL envelope walls are designed as coupled rocking walls. They are located within the east and west envelope walls, so must be considered as potential thermal bridges. The envelope walls (structural walls or light weight walls) have a 25 mm air cavity for ventilation under the exterior cladding sheet.

4.3.5.4 Internal Partitions

The light weight envelope walls and the internal partitions are framed in timber studs with 90 mm fibreglass insulation and gypsum board internal linings.

4.3.5.5 Timber Building Finishes

Figure 4.9 shows the north-east and south-west façade perspective view of the Timber building. The north and south curtain walls, external louvres in north façade, roof and plant room claddings and windows in the east and west façade are the same as in the Concrete and Steel buildings.

Figure 4.9: Timber building, North-east and South-west perspective views.

The light weight envelope walls in the east, west and south façades (including service area envelope walls) are framed in timber studs with 90 mm fibreglass insulation. These walls have a 25 mm air cavity for ventilation built with 25 mm timber battens under fibre cement sheets used as external cladding. Internal finishes are timber framed walls lined with gypsum board plasterboard. Acoustic insulation is required between partitions of the main body of offices. Generally, a plaster acoustic tiled ceiling is used in all office areas.

4.3.5.6 TimberPlus Building Finishes

In the TimberPlus building, all possible ‘common finishes’ of the Timber building were replaced by timber components in order to maximise the use of wood. Figure 4.10 shows the north-east and south-west perspective views of the TimberPlus building.

In the TimberPlus building all aluminium windows frames were replaced by timber (Canadian Western Red Cedar) frames and composite aluminium-cedar frames in the case of the opening windows. Timber louvres in the north facade are another important replacement with the original aluminium louvres replaced by cedar louvres supported in a cedar structure with steel connections (cedar was used also for mullions and transoms and in all parallel louvres outside the curtain wall). Louvres outside the north façade cover the same area as in the Concrete, Steel and Timber buildings and are supported in a cedar timber structure.

The light weight envelope walls in the east, west and south façade (including service area envelope walls) are framed in timber studs with 90 mm fibreglass insulation. These walls have a 25 mm air cavity for ventilation built with 25 mm timber battens under *Pinus radiata* pine weatherboards (www.timber.net.au/flatline). Internal linings are medium density fibreboard (MDF), painted for service and corridor areas and solid finger jointed timber boards inside the offices. The partitions between the main offices are solid timber walls made of five solid timber layers of *Pinus radiata* with a final thickness of 105 mm. MDF panels with a decorative hardwood veneer are used for ceilings in all office areas.

Figure 4.10: TimberPlus building, North-east and South-west perspective views.

Figure 4.11 shows an interior view of the two different types of finish materials used in the office buildings. The top image represents the very common type of office interior finishes used in the Concrete, Steel and Timber buildings. The bottom image shows the internal view of an office in the TimberPlus building. Carpet was applied to both types of finishes but can be potentially replaced by timber flooring (*Parquet*) in the TimberPlus building. These images graphically demonstrate 'common practice' finishes and the variation of this using timber in the case of the TimberPlus lower image.

Figure 4.11: 'Common finishes' of the concrete, steel and timber buildings, compared with the internal finishes of the TimberPlus building.

4.4 Multi-Storey Timber Building Research

This section gives a summary of recent research and development of a new system for construction of multi-storey pre-stressed timber buildings in New Zealand. The system presents opportunities for much greater use of timber and engineered wood products in large buildings, using innovative technologies for creating high quality buildings with large open spaces, excellent living and working environments, and resistance to hazards such as earthquakes, fires and extreme weather events

Whilst none of these timber multi-storey buildings have yet been constructed, the research programme is proceeding rapidly, in close collaboration with industry and government funding agencies.

4.4.1 New Forms of Timber Construction

New forms of pre-stressed timber construction being developed at the University of Canterbury, New Zealand, have the potential to revolutionise large-scale timber buildings. The Timber and TimberPlus buildings described in this report are good examples of this new construction technology.

The new technology can be used for multi-storey timber buildings up to 10 storeys or more. These buildings will have:

- Heavy timber beams, columns, or walls
- Large structural members prefabricated off site
- Main timber structure of LVL members
- Post-tensioned connections for easy construction and high seismic resistance
- Removable partitions and cladding
- Composite T-beam floors with concrete topping on timber joists

The performance requirements for these buildings will be:

- Wide open spaces, with maximum flexibility of use.
- Residential, educational or commercial uses, which can be changed over time.
- Safety in fire, earthquakes, or extreme weather events.
- Excellent acoustic performance.
- Excellent thermal behaviour.
- Durability for hundreds of years.
- Low levels of life-cycle energy use, hence low CO_2 emissions during construction, long-term use, and demolition.

4.4.2 Development of Post-Tensioned Timber Systems

Recent research work at the University of Canterbury has extended the concept of hybrid multi-storey building systems from pre-cast concrete to timber frame and wall systems.

During the 1990s, investigations in pre-cast concrete moment-resisting frames or interconnected shear walls under the U.S. PRESSS (Pre-cast Seismic Structural System) programme resulted in the revolutionary development of high-performance, cost-effective, seismic resisting systems. These solutions can undergo inelastic displacements while limiting structural damage and assuring full re-centreing capability after a seismic event (no residual/permanent deformations). These innovative solutions, typically referred to as *jointed ductile connections* or PRESSS-technology, differ from monolithic solutions (i.e. cast-in-place reinforced or pre-cast concrete; welded or bolted connections in steel) in that:

a) Prefabricated structural elements are connected using unbonded post-tensioning;
b) The inelastic seismic demand is accommodated within the connection through the opening and closing of an existing gap
c) The structural elements are kept in the elastic range with a very limited level of damage.

A particularly efficient solution is provided by the *hybrid* system where an adequate combination of self-centreing capacity (unbonded tendons plus axial load) and energy dissipation (mild steel or other dissipation devices) leads to a controlled rocking motion under seismic action.

This pre-cast concrete technology has been successfully adapted for timber frame and wall systems. Due to its high homogeneity and good mechanical properties, laminated veneer lumber (LVL) has been selected as the preferred engineered wood material.

Figure 4.12 shows the conceptual solution for a hybrid beam-column timber connection, based on the combination of post-tensioning and internal dissipaters (e.g. epoxied mild steel bars).

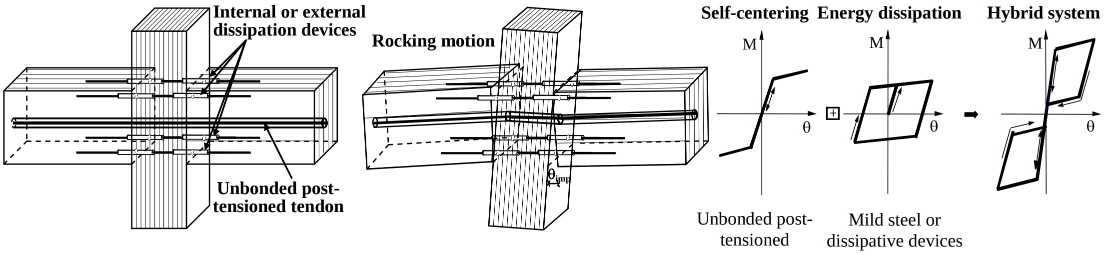

Figure 4.12. Basic concept of hybrid jointed ductile connections for LVL timber frame systems and flag-shape hysteresis behaviour [3].

4.4.3 Experimental Investigation

The University of Canterbury has carried out extensive experimental tests on timber exterior beam-column subassemblies, cantilever columns, single walls and coupled walls. Typical test-setups are shown in Figure 4.13.

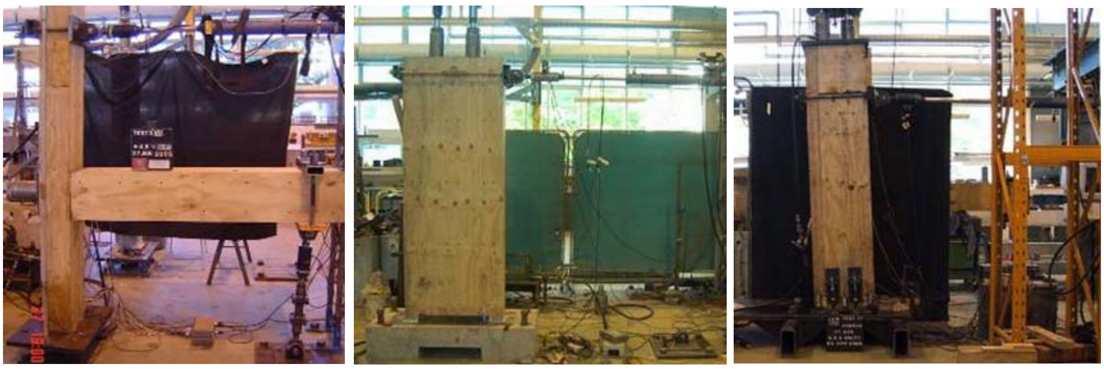

Figure 4.13. Test set-up of exterior beam-column joint, (single) cantilever wall, cantilever column specimens.

Several different solutions have been developed for energy dissipation devices. Because the dissipaters are the only damageable part of the connection system, improved post-earthquake reparability leads to significant reductions in repair costs and business downtime compared to traditional solutions in timber construction (e.g. nailed, bolted, or steel dowel connections).

In general terms, the experimental results on different frame or wall systems and sub-assemblies confirmed the high seismic performance of these innovative jointed ductile timber connections based on post-tensioning techniques. In all cases, considering different simulations of seismic loading, the tested systems demonstrated large inelastic displacements (high ductility demand) with no significant damage of the structural elements and negligible residual deformations.

4.4.3.1 Design Flexibility

The hybrid systems described above allow for great flexibility in the seismic design of multi-storey timber buildings, as confirmed by the different arrangements investigated, with different types of dissipaters combined with different initial post-tensioning of the tendons.

Research to evaluate the losses of pre-stressing force in the tendons over time due to creep of the timber is ongoing.

The floor system is a key component of the multi-storey timber building. There are a number of performance requirements that must be satisfied:

- resistance to gravity load (strength limit state for out-of-plane loading)
- control of vibration and deflection due to gravity load (serviceability limit state)
- resistance to lateral load (strength limit state for in-plane loading)
- control of deflection due to lateral load on the diaphragm (strength and serviceability limit state)
- fire resistance
- acoustic separation
- thermal insulation

The Timber and TimberPlus buildings both use a concrete-timber composite flooring system. Whilst traditional joist floors are extensively used for single- or two-storey houses, they meet few of the above performance requirements. Stressed skin panels flooring systems exhibit improved structural performance, however they still suffer from the problem of vibrations for long-span floors and cannot provide adequate acoustic separation.

Concrete-timber composite systems were initially proposed in Europe for strength and stiffness upgrading of existing timber floors. Now, due to several advantages, such as lower weight than traditional reinforced concrete floors, and better acoustic performance than timber-only floors, the composite systems are being used for new construction. The larger stiffness of the concrete topping markedly increases the flexural stiffness of the composite system which reduces the deflection and the sensitivity to vibrations. It is possible to construct medium to long-span (6 to 10 m) floors significantly lighter than pre-cast concrete counterparts with similar performance. Particularly important is the increase in acoustic separation over traditional timber-only floor, which is a crucial requirement for inter-tenancy floors.

A design feature of the Timber and TimberPlus buildings is prefabrication. The floors could be constructed from composite panels entirely prefabricated off-site or by connecting concrete slabs prefabricated off-site onto the timber joists and the adjacent slabs.

An extensive experimental programme is currently ongoing at the University of Canterbury, New Zealand and the University of Technology, Sydney including tests to failure and long-term tests of full scale concrete-LVL composite beams and different connection details, dynamic vibration tests of composite beams, and tests under repeated loads of composite beams and different connection details.

The possibility of using pre-stressed LVL beams with composite connections to the concrete topping will also be investigated after good results of a preliminary study.

4.4.3.2 Long-term Effects

Durability

Durability has been a problem in multi-storey light-timber-frame buildings in New Zealand, with inadequate weather-proofing details leading to rapid decay of untreated timber studs in concealed wall cavities. This problem is being solved with stringent new design and inspection procedures. There are also new requirements for using chemical treated timber in structural elements that may become wet due to weather exposure. Durability is not expected to be a problem in the new commercial buildings using large scale beams, columns and walls, provided that attention is paid to weather-proof cladding materials and the main structural elements are visible for inspection.

Creep tests

An extensive experimental programme aimed to investigate the long-term behaviour of pre-stressed LVL beams is currently in progress. The programme includes creep tests of small LVL blocks, loaded in compression parallel and perpendicular to grain, creep tests of portions of two-bay LVL frames, where the beams are pre-stressed with unbonded tendons, and creep tests of LVL beams, with and without pre-stressing, subjected to gravity load. Preliminary results have shown a moderate (about 10%) reduction of pre-stressing force due to time-dependent phenomena over one year. These results will be reported soon.

Fire safety

The fire safety aspects of multi-storey timber buildings is being assessed in accordance with New Zealand and international codes, considering both internal and external growth and spread of fire, also structural fire resistance of the floors and main structural members. Since 1992 the New Zealand Building Code has allowed timber buildings of unlimited height provided that performance requirements are met, whereas earlier codes limited height to only three storeys.

5 Operational Energy

5.1 General

This section presents the data setup used in the operational energy simulation process, describes the thermal envelope configuration of the four alternative building designs, provides a description of the heating, ventilation and air conditioning (HVAC) systems used, the lighting systems and the schedule for simulations.

Figure 5.1 shows the floor plan used for the Concrete, Steel, Timber and TimberPlus buildings. It also shows a transverse cross-section through the ventilation chimneys. The floor is subdivided into four zones; three offices and one corridor and services area on the south side.

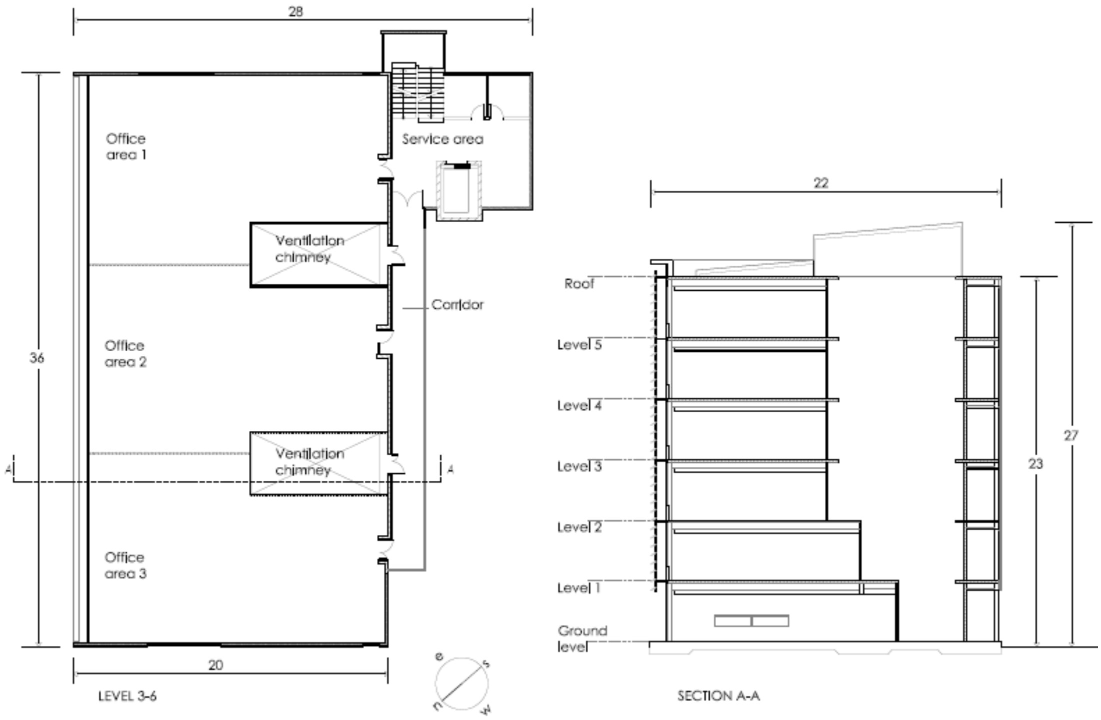

Figure 5.1: Plan used for energy calculations, and cross-section through the ventilation chimneys.

For operational energy modelling, only the office zones have HVAC control. The corridors and service areas only have manually opening windows, set for natural ventilation. Two large ventilation chimneys were placed in the actual Concrete design for the Biological Sciences laboratory building, and these are retained in the four case study designs considered in this report. The ventilation chimneys are continuous through all floors, from ground level up to the plant room on the roof slab. They are used for natural ventilation with automatically controlled louvres set to be opened between 22°C and 26°C. When the louvres are closed, the air conditioning keeps the temperature at 26°C until 6pm.

Of central importance to the design of the research covered by this report was the requirement to have all four alternative designs displaying very similar operational energy consumption over the lifetime of the buildings. Several previous researchers have found that even when the energy efficiency of buildings being compared is code-compliant, the effects of the embodied energy of construction materials are difficult to discern and negligible in comparison to the much larger variations in operational energy between the different buildings (Cole and Kernan (1996); Page (2006); Sartori and Hestnes (2007); Suzuki and Oka (1998)).

Similar operational energy consumption of the four buildings being compared in this report means that the differences in the environmental impacts are determined by the differences in the embodied and recurrent (maintenance and refurbishment) energy and GWP emissions in the different materials used in each building.

To achieve very similar operational energy profiles required different design for envelope walls construction, thermal mass, and heating and cooling equipment in each of the four buildings.

An energy performance simulation was undertaken to assess the operational energy use of all four building. The energy simulation was initially undertaken for the Concrete building using Design Builder software (2008). Design parameters were varied, trialling different equipment, materials and data sets until a satisfactory operational energy profile was achieved; a profile typical of a multi-storey office building in Christchurch.

This energy consumption profile was then used as a benchmark energy target for the alternative Steel, Timber and TimberPlus buildings. Iterative energy simulations following changes in design features (for example, selection of improvement in envelope walls construction and some changes in finishes) were undertaken with each of the alternative buildings, aiming to reach the benchmark set by the Concrete building. Once the 'Concrete' benchmark was reached, final simulations were carried out to assess the small differences between the energy performances of each of the four buildings.

5.2 Operational Energy Simulation

5.2.1 Simulation Method

The Concrete building was designed initially to have low energy consumption, and to perform better than the minimum requirements of New Zealand Standard NZS 4243 Energy Efficiency – Large Buildings (NZS). Subsequently, all four buildings in this research had similar performance profiles (close to 86 kWh/m^2/year). This is particularly important because one of the aims of this research was to look at the influence of materials on the life cycle energy use and GWP emissions of the buildings.

For the simulations carried out in this study, many of the inputs (Table 5.1) are default data based on NZS 4243 but some data from the Design Builder software library database was also used as input (NZS (1996)). A Wellington based engineering company *eCubed Building Workshop Ltd*[2] was involved to supervise the simulation process.

[2] [2] e-Cubed Building Workshop Ltd. synthesises traditional mechanical and electrical services engineering design with new trends in sustainable design. Service is based upon an extensive local and international track record in applying sustainable principles to engineering services design. The e-Cubed sustainable design service works alongside the architect and the traditional engineering consultants to develop a sustainable design framework and concepts which are refined and tested by the use of advanced modeling tools with the aim of reducing energy and water use by 40-50% when compared to a conventional solution.

Table 5.1: Simulation inputs values

Data	Value	Unit	Source
Metabolic Rate	0.9	Met	Ashrae comfort tool
Occupancy	0.1	People/m^2	NZS 4243
Plug Load (Office Equipment)	8	W/m^2	NZS 4243
Heating set point	22	Celsius	E Cube
Natural ventilation	24	Celsius	E Cube
Cooling set point	26	Celsius	E Cube
Min. fresh air	8	l/s - person	NZS 1330
Lifts	4	kWh/m^2	NZGBC
Infiltration	0.25	ACH*	NZGBC
DHW	4	kWh/m^2	NZGBC
Lighting	400	Lux	AS/NZS 1680.1:2006
Lighting power density	13.6	W/m^2	DesignBuilder

During the design process, changes to improve performance were mostly related to variation of thermal mass and the improvement of the thermal envelope and for example by adding insulation to the roof slab.

5.2.2 Floor Areas for Simulation

The analysis of the results of this research used the net usable area. The ventilation system occupies a large area of space within the building; the large vertical void areas used as chimneys connected to a plant room on the roof were taken out of the gross floor area for the calculation of the net usable area.

Table 5.2 shows the initial gross floor area (calculated inside the envelope walls), then segregated in floor area allocated to the ventilation chimneys and plant room, offices and corridors floor area. Finally, Table 5.2 shows the net usable area which was calculated adding the office floor area plus corridors floor area.

Table 5.2: Calculation of the Net Usable Area for the analysis of results

Gross floor area	**4,247 m^2**
Chimneys and plant room	711 m^2
Offices	2,745 m^2
Corridors	792 m^2
Net usable area (Offices + Corridors):	**3,536 m^2**

Initially, the net usable area was used for the calculation of the operating energy consumption intensity per square metre. Subsequently, in order to have a single result for life-cycle energy consumption per square metre, the initial and recurrent embodied energy were subdivided also for net usable area. All results with reference to the intensity of energy per square meter are presented in net usable area.

5.2.3 Buildings' Thermal Envelope Descriptions

Table 5.3 shows the different construction of the office area envelope walls, including wall thickness, R/values (heat loss) and the percentage of the section of each wall configuration type within the total wall for each of the walls involved in the envelope of the main body of offices, for each of the Concrete, Steel, Timber and TimberPlus buildings. This information is of importance because only the office areas use HVAC (mixed with natural ventilation), so there is significant energy consumption required to keep a comfortable range of temperature inside those areas, with heat losses through walls having a particularly large impact.

As seen in Table 5.3, a significant difference between the Concrete building (with high thermal mass) and the three other buildings (with lower thermal mass) - Steel, Timber and TimberPlus - is that the Concrete building has a much thicker wall in the east and west facades (*Thermomass*) than the east or west facades of the Steel, Timber or TimberPlus buildings. Despite this much greater thickness, the R/Values are lower for the Concrete building than for the Steel, Timber and TimberPlus buildings. The wall description in all four buildings is segregated into cavity walls and structural walls.

All light weight envelope walls in the Steel, Timber and TimberPlus buildings, including the south façade internal wall of the Concrete building, have 90 mm thick fibre-glass insulation. There was no variation in the thickness of insulation between any buildings, so the final R/value differences between light weight walls is due to the influence of different linings, claddings and air cavity thicknesses. The TimberPlus building normally has higher R/values than the Timber building, due to timber external claddings and interior linings.

Table 5.3 is a summary of detailed wall specifications. Total R/Values were calculated by the DesignBuilder software used for simulations.

When looking at light weight walls in any of the four buildings, the *cavity* is the section of the wall that contains insulation between the internal linings and the external air cavity under the cladding, and the *structure* is the section of the wall that contains the studs and nogs (blocking) all added together, acting as a thermal bridge. In the case of the Steel building, the part of the wall structure acting as a thermal bridge is only the web of the cold-rolled steel channel used as studs. On the other hand, in a timber frame wall, the area acting as a thermal bridge is the complete timber stud width. Nevertheless, thermal conductivity is much higher in steel (45.3 W/mK) than in timber (0.11 W/mK) so the incidence of the small portion of steel in a steel framed wall is as significant as a much larger portion of wood in a timber framed wall (ASHRAE American Society of Heating, 2005).

Because of the high thermal conductivity of steel, the main structural system of the steel building was left inside the offices and not within envelope walls so it doesn't drastically increase the heat losses. On the other hand, in the Concrete, Timber and TimberPlus buildings, the structural systems are rather similar and the shear walls are part of the structural system. This means that in the east and west facades, the structural walls are part of the envelope walls, somewhat decreasing the total R/Value. In the Concrete building, there is a layer of extruded polystyrene in the core of the structural walls but in the Timber and TimberPlus buildings no extra insulation has been added to the shear walls. The influence of structural components on the thermal envelope is the main reason why all four buildings cannot have exactly the same R/Value, even when the same insulation is used.

Table 5.3: Areas of office envelope walls including thickness and R/values for the Concrete, Steel, Timber and TimberPlus buildings.

Wall construction	Thicknees	R/Value	% in wall
1 Concrete building			
East and West facades: Concrete / Thermomass	310 mm	**2.02**	100 %
South facades: Concrete / Thermomass	310 mm	**2.02**	22 %
Light weight envelope wall / cavity	137 mm	**2.68**	73 %
Light weight envelope wall / structure	137 mm	**1.50**	6 %
North Façade: Glassing Courtain wall	50 mm	**0.56**	100 %
Roof: Concrete / roof Floor (ceiling incl)	814.5 mm	**2.59**	100 %
Internal floor: Concrete / Internal Floor (ceiling incl)	814.5 mm	**0.79**	100 %
Ground floor: Concrete / Ground Floor	1327 mm	**2.80**	100 %
2 Steel Building			
East and West facades: Light weight envelope wall / cavity	138.5 mm	**2.65**	97 %
Light weight envelope wall / structure	138.5 mm	**0.23**	3 %
South facades: Light weight, south wall / cavity	147 mm	**2.68**	97 %
Light weight, south wall / structure	147 mm	**0.25**	3 %
North Façade: Glassing Courtain wall	25 mm	**0.56**	100 %
Roof: Steel / Roof slab (ceiling incl)	814.5 mm	**2.47**	100 %
Internal floor: Steel / Internal floor (ceiling incl)	814.5 mm	**0.67**	100 %
Ground floor: Concrete / Ground Floor	1327 mm	**2.80**	100 %
3 Timber Building			
East / West / south facades: LVL Shear Wall	286 mm	**2.06**	72 %
Light weight envelope wall / cavity	137 mm	**2.68**	27 %
Light weight envelope wall / structure	135 mm	**1.50**	1 %
South facades: Light weight envelope wall / cavity	137 mm	**2.68**	90 %
Light weight envelope wall / structure	135 mm	**1.50**	10 %
North Façade: Glassing Courtain wall	25 mm	**0.56**	100 %
Roof: Timber / Roof slab (ceiling incl)	864.5 mm	**2.58**	100 %
Internal floor: Timber / Internal Floor (ceiling incl)	814.5 mm	**0.78**	100 %
Ground floor: Concrete / Ground Floor	1327 mm	**2.80**	100 %
4 Timber Plus Building			
East and West facades: LVL Shear Wall	331 mm	**2.42**	72 %
Light weight envelope wall / cavity	144 mm	**2.81**	27 %
Light weight envelope wall / structure	144 mm	**1.23**	1 %
South facades: Chimney, south wall / cavity	149 mm	**2.84**	90 %
Chimney, south wall / structure	149 mm	**1.23**	10 %
North Façade: Light weight envelope wall	144 mm	**2.84**	30 %
Glassing Courtain wall	25 mm	**0.56**	70 %
Roof: Timber / Roof slab	864 mm	**2.58**	100 %
Internal floor: Timber / Internal Floor	814.5 mm	**0.78**	100 %
Ground floor: Concrete / Ground Floor	1327 mm	**2.80**	100 %

5.2.4 HVAC

For all four buildings, the HVAC system operates when the inside temperature is below 22 °C and above 26°C. Between 22 °C and 26°C the buildings all work under a natural ventilation mode with no heating or cooling. The building designs include two internal ventilation chimneys that under natural ventilation mode and are set in simulation to exhaust the air coming into the buildings through opening windows in the curtain wall of the north façade.

The HVAC system used in the simulations (chosen from many default possibilities in DesignBuilder) was hot water radiators for perimeter heating and mixed-mode between natural ventilation and mechanical HVAC. Above 26°C, air conditioning keeps the temperature constant and below 22°C, heating warms the building.

5.2.5 Schedule

All four buildings were simulated as typical office buildings, using schedules for simulation based on NZS 4243. Three schedules were developed to determine the percentage of loads for items such as occupancy, plugs, lighting and equipment and HVAC operation.

Table 5.4 summarises the simulation load level.

Table 5.4: Schedule for HVAC simulations (figures represent percentage of assigned load).

		12-8am	8-11am	11-6pm	6-10pm	10-12am
1	**Occupancy**					
	Week	0	95	95	5	0
	Saturday	0	10	5	0	0
	Sunday	0	5	5	0	0
2	**Plug and Lighting**					
	Week	5	90	90	30	5
	Saturday	5	30	15	5	5
	Sunday	5	5	5	5	5
3	**Operation HVAC Typical NZ office**					
	Week	0	100	100	0	0
	Sunday	0	0	0	0	0

5.2.6 Energy sources

Natural gas is used as fuel for the heating system and domestic hot water. Electricity is used for cooling, lighting and office equipment energy. The outcome of the operational energy simulations produced results which showed the annual fuel consumption segregated into natural gas and electricity.

This energy mix is important when considering GWP since two buildings having the same total energy might use different proportions of gas and electricity. Thus buildings with the same total operational energy use may not result in the same GWP emissions, as LPG has a much higher CO_2 coefficient than electricity.

5.3 Life-Cycle Operational Energy Use

An energy performance simulation was undertaken to assess the operational energy consumption of each of the four alternative building designs which were designed to have very similar operational energy consumption.

The underlying difference between operational energy consumption between the buildings is mostly due to the amount of concrete (acting as thermal mass) involved in each building.

Modifying the design to achieve similar operational energy consumption is then achieved through changes to the insulating materials, thermal mass and heating and cooling equipment in each of the four buildings

The difference in energy consumption between the Timber and TimberPlus buildings is due to the influence of solid wood in the partitions, external walls and ceiling acting as thermal mass, storing and exchanging heat (Bellamy and Mackenzie, 2007) and also because the TimberPlus building normally has higher R/values than the Timber building, due to timber external claddings and interior linings.

With similar operational energy consumption, the final life-cycle energy consumed and GWP emissions would be determined by the differences in the embodied and recurrent energy and GWP emissions in the materials used in each building.

Even when buildings aimed for similar operating energy consumption, small differences still existed. The following provides summary results of the energy consumption simulations.

Table 5.5 shows the total annual operational energy consumption of the Concrete, Steel, Timber and TimberPlus buildings. Operational energy is derived from either electricity or gas, and the total final consumption is divided by the net useable floor area (measured inside external walls).

Table 5.5: Operational energy annual results

Total annual energy use in operation	kWh	GJ	Difference against lowest consumption %	Difference against lowest consumption GJ
1 Concrete building				
Total electricity	241,171 kWh	868 GJ		
Total Gas	55,764 kWh	201 GJ		
Total energy use:	**296,935 kWh**	**1,069 GJ**	0 %	0 GJ
Total energy use/m²:	**84 kWh/m²**	**0.30 GJ/m²**		
2 Steel building				
Total electricity	245,999 kWh	886 GJ		
Total Gas	56,365 kWh	203 GJ		
Total energy use:	**302,363 kWh**	**1,089 GJ**	2 %	20 GJ
Total energy use/m²:	**86 kWh/m²**	**0.31 GJ/m²**		
3 Timber building				
Total electricity	257,433 kWh	927 GJ		
Total Gas	53,934 kWh	194 GJ		
Total energy use:	**311,367 kWh**	**1,121 GJ**	5 %	52 GJ
Total energy use/m²:	**88 kWh/m²**	**0.32 GJ/m²**		
4 Timber-Plus building				
Total electricity	247,271 kWh	890 GJ		
Total Gas	57,470 kWh	207 GJ		
Total energy use:	**304,740 kWh**	**1,097 GJ**	3 %	28 GJ
Total energy use/m²:	**86 kWh/m²**	**0.31 GJ/m²**		
Net usable area		**3,536 m²**		

The total annual operational energy consumed in the four buildings is fairly similar. The highest difference (5%) is between the Concrete and the Timber building

When energy consumed is divided by the building's gross floor area, the Concrete building uses 84 kWh/m^2/yr, followed by the Steel and the TimberPlus buildings, both using 86 kWh/ m^2/yr, and the Timber building, using 88 kWh m^2/yr. The difference between the Concrete building (lowest operating energy consumption) and the Timber building (largest operating energy consumption) is about 4 kWh/ m^2/yr.

Electricity accounts for roughly 85% of the total energy consumed, with gas accounting for the remaining 15%. This is because gas is used only for heating and domestic hot water while electricity is used for cooling, lighting, room electricity and miscellaneous systems (mainly lift).

Table 5.6 shows the life-cycle operational energy use for the Concrete, Steel, Timber and TimberPlus buildings (the annual operational energy multiplied by a 60 year life-cycle). The life-cycle energy consumption is presented in GJ and the total is then divided by the buildings net useable floor area (measured inside external walls).

Table 5.6: Energy consumed in operations, annual and 60 year life cycle consumption in GJ

Annual energy consumed in operation			60 years life-cycle
	kWh	GJ	GJ
1 Concrete building			
Total energy use:	296,935 kWh/yr	1,069 GJ/yr	64,138 GJ/yr
Total energy use/m^2:	84 kWh/m^2.yr	0.30 GJ/m^2.yr	18.1 GJ/m^2.yr
2 Steel building			
Total energy use:	302,363 kWh/yr	1,089 GJ/yr	65,310 GJ/yr
Total energy use/m^2:	86 kWh/m^2.yr	0.31 GJ/m^2.yr	18.5 GJ/m^2.yr
3 Timber building			
Total energy use:	311,367 kWh/yr	1,121 GJ/yr	67,255 GJ/yr
Total energy use/m^2:	88 kWh/m^2.yr	0.32 GJ/m^2.yr	19.0 GJ/m^2.yr
4 Timber-Plus building			
Total energy use:	304,740 kWh/yr	1,097 GJ/yr	65,824 GJ/yr
Total energy use/m^2:	86 kWh/m^2.yr	0.31 GJ/m^2.yr	18.6 GJ/m^2.yr

5.3.1 Benchmarks for Operational Energy in New Zealand Buildings

Several researchers have studied the energy consumption of commercial buildings in New Zealand – hence, there are a number of benchmarks for operational energy in office buildings in New Zealand.

The benchmark studies below provide comparison of the results with those produced from the operational energy simulations undertaken for each of the four buildings in this report. This confirms that all four buildings are low energy consumption buildings.

- Standards New Zealand (NZS) 4220.

  "Code of practice for energy conservation in non-residential buildings" (1982). This standard sets energy consumption targets for New Zealand's existing and new buildings. The target for office buildings is: existing buildings 200 kWh/m^2/yr and new buildings 100 kWh m2/yr.

- Property Council of New Zealand.

  The table below summarises the findings of report published by The Property Council of New Zealand in 2000: *Energy consumption benchmarks: An analysis of the energy expenses incurred by New Zealand CBD office buildings.*

  This study was undertaken to asses the cost and level of energy consumption in commercial CBD office buildings throughout New Zealand. The survey was undertaken over the 1998 and 1999 calendar years. The survey obtained the annual energy consumption statistics of 35 CBD office buildings encompassing approx 410,000 m^2 of net lettable area (the gross area less common areas and ancillary spaces).

  The study produced an energy performance indicator, the Energy Use Index (EUI) which provides a reference for a building's energy consumption (in kWh/m^2/yr of NLA) of several buildings occupancy types. Table 5.7 shows the EUI values for office buildings with different indoor climate control systems.

Table 5.7: Property Council of New Zealand, 2000 Energy Use Index.

Office building	Low	Typical	high
With HVAC	200 kWh/m^2/yr	280 kWh/m^2/yr	400 kWh/m^2/yr
Natural ventilated	100 kWh/m^2/yr	210 kWh/m^2/yr	300 kWh/m^2/yr
Tenant electricity only	60 kWh/m^2/yr	150 kWh/m^2/yr	200 kWh/m^2/yr

- NZ Green Building Council.

  The NZGBC offers the newest energy use target with the New Zealand Green Star Office Rating Tool. Green Star was launched in 2007 and rates the "sustainability" of new and refurbished office buildings in New Zealand. It is a *Conditional Requirement* for obtaining a NZ Green Star rating that the base building design achieves an energy use figure of 120 kWh/ m^2/yr or less, using the modelling method in NZS 4243/4218 (NZ Green Building Council, 2008).

5.3.2 Summary of Energy Consumption Benchmarks

The predicted average energy consumption of the Concrete, Steel, Timber and TimberPlus buildings analysed in this report is 86 kWh/m^2/yr. There is a tendency in simulations that the outcomes produced are lower than the audited energy consumption during occupancy. It is not the aim of this report to identify the reasons for the gap between the predicted and audited outcomes. However, a figure of 84-86 kWh/m^2/yr is well below all the above benchmarks.

5.4 Masters Thesis

The Master in Building Science thesis *"The influence of construction materials on the life cycle energy use and carbon dioxide emissions of medium sized commercial buildings"* by Nicolas Perez (2008) provides much greater detail about the operating energy of the four buildings covered by this report, including detailed information on;

- Operating energy segregated into end-uses (cooling, heating, DHW, system miscellaneous (lift), lighting and room electricity).
- Annual energy consumption – heating versus cooling.
- Comparison between the Concrete and Timber buildings as examples of high and low thermal mass buildings respectively.

6 Life Cycle Assessment

6.1 Introduction

This section of the report investigates some of the environmental impacts of the four alternative building designs through the use of Life Cycle Assessment (LCA).

This work was carried out by Scion, a New Zealand Government Crown Research Institute (CRI).

6.2 Background

Life Cycle Assessment (LCA) is the central theme of this research project. However, the LCA study is dependent on research and results obtained from other parts of the overall project, undertaken prior to the LCA. The necessary steps before being able to undertake the LCA study are summarised below;

1. The design of four buildings – Concrete, Steel, Timber and TimberPlus.
2. The quantification of the construction materials used in each building.
3. Operational energy modelling and results for each design.

Building on the above research, the LCA study compares the lifetime primary energy consumption and the global warming potential (GWP) of the four buildings and investigates the environmental hotspots of each building.

6.2.1 LCA Overview

Life Cycle Assessment is based on the concept of Life Cycle Thinking which integrates consumption and production strategies over a whole life cycle, so preventing a piece-meal approach to systems analysis. Life cycle approaches avoid problem-shifting from one life cycle stage to another, from one geographic area to another, and from one environmental medium to another.

Life Cycle Assessment is an analytical tool for the systematic evaluation of the environmental impacts of a product or service system through all stages of its life. It extends from extraction and processing of raw materials through to manufacture, delivery, use, and finally on to waste management. This is often referred to as “cradle to grave”. A number of other environmental assessment tools are restricted to the production process, which is sometimes called “gate to gate”, or in the case of embodied energy covers the life cycle from “cradle to gate” without taking the end-of-life into account.

6.2.2 Definition of LCA

ISO 14040 defines LCA as:
“… a technique for assessing the environmental aspects and potential impacts associated with a product, by

- *compiling an inventory of relevant inputs and outputs of a product system;*

- *evaluating the potential environmental impacts associated with those inputs and outputs;*
- *interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.*

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences."

6.2.3 Elements of an LCA

An internationally accepted framework for LCA methodology is defined in AS/NZS ISO 14040 and 14044. These standards define the generic steps which have to be taken when conducting an LCA. The following section will explain these steps and give examples on how they can be applied to the building industry.

Four different phases of LCA can be distinguished:

6.2.3.1 Goal and Scope Definition

The goal and scope of the LCA study are clearly defined in relation to the intended application. This includes a detailed description of the reasons for undertaking the study, as well as the intended audience and the intended application of the results.

Having defined the goal of the study, scoping involves defining the functional unit, system boundaries and other requirements for the study, such as data quality, and choice of environmental impacts to be analysed in the "impact assessment".

6.2.3.2 Inventory Analysis

The inventory analysis involves the actual collection of data and the calculation procedures. The relevant inputs and outputs of the analysed product system are quantified and produced as a table. These are the material and energy inputs, and product and emission outputs to air, water and land.

In an LCA, the material and energy flows should be "*drawn from the environment ... or discarded into the environment without ... human transformation*" [ISO 14040]. Thus the overall product system should extend upstream to primary resources, and downstream to the point where material is emitted into the environment in an uncontrolled way.

The initial phase is to develop an "input-output" table of the product systems. This would, for example, be a kg of concrete, kWh of electricity used and km of transport, including the litres of diesel consumed. A detailed inventory is then compiled; for concrete this includes the amount of gravel, sand, crude oil and all related emissions, e.g. kg of CO_2 emissions.

At the end of the life cycle, treatment of solid waste should be considered as part of the product system. This means that 'waste' does not leave the product system analysis but is dealt with within the system boundaries.

6.2.3.3 Impact Assessment

The impact assessment translates the results of the inventory analysis into environmental impacts (e.g. climate change, ozone depletion). The aim of this phase is to evaluate the significance of potential environmental impacts.

The contribution to climate change is, for example, expressed as the Global Warming Potential (GWP). GWP is defined over a certain time period to reflect the relative lifespans of each greenhouse gas in the atmosphere - in this project the time period used is 100 years. This is a standard time period defined by the IPCC. In order to calculate the GWP, all emissions contributing to climate change that are listed in the inventory table, e.g. carbon dioxide and methane, are converted into kg CO_2 equivalents. The following methodology is applied: CO_2 has a weighting of 1 kg CO_2 equivalent whereas the more potent greenhouse gas methane has a value of 25 kg CO_2 equivalents (IPCC, 2007), in other words 1 kg of methane contributes 25 times as much to global warming as 1 kg CO_2. In this way it is possible to add up the results of all emissions which contribute to the same environmental impact category.

6.2.3.4 Interpretation

In this phase conclusions and recommendations for decision-makers are drawn from the inventory analysis and the impact assessment.

These can be represented as shown in Figure 6.1. In practice, LCA involves a series of iterations as its scope is redefined on the basis of insights gained throughout the study.

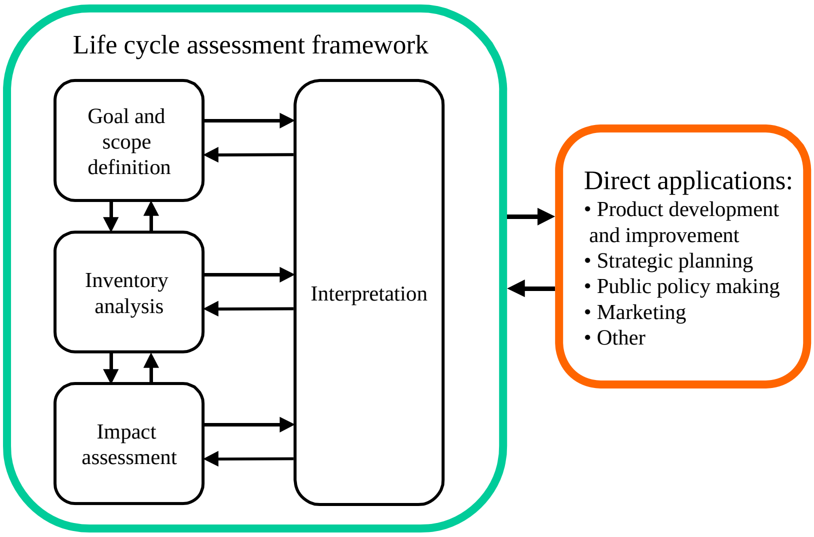

Figure 6.1 LCA framework (ISO 14040)

6.3 Life Cycle Assessment of the Four Building Designs

6.3.1 Goal

The goal of this study is to calculate the environmental impacts (energy consumption and Global Warming Potential) of four alternative designs of a theoretical office building located on the University of Canterbury campus.

The four designs are composed of three different structural materials; Concrete, Steel and Timber. In addition a variant called TimberPlus has been examined, in which the use of wood has been maximised to the highest practical level.

The study includes the initial production of the required materials to construct the building, a maintenance schedule where some building materials are replaced over the lifetime of the building, impacts related to the operational energy, and the end-of-life of the four buildings.

In addition to the overall goal, scenario analysis and sensitivity tests were carried out. The scenario analysis examined different end-of-life scenarios, as well as the impact of different locations of the buildings with regard to changes in transport distances.

The end-of-life scenarios include a base scenario where all waste is landfilled compared with a scenario in which the building materials are reused. This includes combustion of all wood materials and recycling of structural concrete and steel. Scenarios for transport distances look at the location of the building in Christchurch (base scenario), Wellington, and Auckland.

The end-of-life and transport scenarios are described in more detail in sections 6.3.3.3 and 6.3.3.4.

Finally, the results of the study are analysed and compared with an assessment of the buildings using the current Green Star NZ assessment tool introduced by the New Zealand Green Building Council (NZGBC). Green Star NZ is an environmental rating system for buildings. Green Star for office buildings was released in April 2007 and evaluates building projects against eight environmental impact categories, plus innovation. The goal of this analysis is to show how the same commercial building would rate using Green Star compared to a life cycle based approach, as it is applied in Life Cycle Assessment.

6.3.2 Scope

The scope of the study includes a clear description of the system under analysis, the functional unit, system boundaries and data quality as well as the intended audience and application of the results.

6.3.2.1 Functional Unit

The results of the study are related to an office building with gross area 4,247 m^2 on six floors, located in Christchurch and used over a period of 60 years. Four designs of the building have been considered.

6.3.2.2 System Boundaries

The system boundaries applied in this study were "cradle to grave", which means that all impacts of manufacturing the building products, their transport, the use phase of the building, and the disposal of the product after its useful life were considered. Upstream processes such as the production of diesel used in transport as well as the emissions of the truck have been taken into account, including all related environmental impacts. This also applies to the provision of natural gas for heating and electricity.

The actual construction and demolition of the building are not taken into account because they are considered to be negligible (Kellenberger and Althaus, 2008).

The results of the study are shown for the following stages of the life cycle:

- production of building materials
- transport to building site
  - base scenario: building located in Christchurch
  - alternative scenarios: Wellington and Auckland
- use of building over 60 years
  - maintenance
  - electricity for lighting, heating, appliances and cooling
  - natural gas for heating and hot water
- transport of demolition materials to landfill or recycling
- end-of-life
  - base scenario: landfill
    - including operation of landfill, e.g. bulldozers to shift material on landfill.
    - carbon storage (sequestration) of timber, taking into account some decay and release of carbon in form of carbon dioxide or methane.
  - reutilisation scenario – combustion of all timber in cogeneration to produce heat and electricity which displace electricity from the NZ grid and heat from natural gas as well as recycling of all structural concrete and steel.

All stages of the life cycle as well as the scenarios are described in detail in the inventory analysis.

6.3.2.3 Data Quality

Two aspects with regard to data quality need to be considered:

- input – output data, i.e. quantities of materials used and transport distances
- life cycle inventory data, i.e. emissions and energy required for the production of the materials or generation of electricity

The data quality for both aspects of this research report can be described as high quality data.

The input-output data is based on calculations - because the study has been undertaken for four theoretical buildings, the material consumption could not be measured on site.

The life cycle inventory data used in this study is from two key sources:

The data for most building materials is based on a new dataset that has been developed as part of the project “Life Cycle Assessment: Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand” by Nebel et al. (2009). In this project European-based industry data was combined with New Zealand specific data, compiled and calculated by Alcorn (1995, 1998, 2003) at the Centre for Building Performance Research at Victoria University.

Data for materials that are not included in this dataset are based on data that is part of a LCA software package (GaBi 4.3) and is based on European industry data. The data has been amended and checked for consistency with literature data (GaBi 2006) and is compliant with the ISO Standards 14040 and 14044. The documentation of the data describes the production process, applied boundary conditions, allocation rules etc. for each product. The data covers resource extraction, transport, and processing, i.e., “cradle to gate”. Included are material inputs, energy inputs, transport, outputs and as well as the emissions related to energy use and production. Capital equipment is excluded[3].

A New Zealand specific dataset for the provision of electricity is provided in the GaBi database, based on the average GridMix of 2004.

6.3.2.4 Intended Audience and Application of the Results

The study was undertaken for the Ministry for Agriculture and Forestry. It is anticipated that the results will be used to inform policy making. The results can also be used to demonstrate the benefits of a life cycle approach when comparing different building designs.

6.3.2.5 Impact Assessment Methodologies

Primary energy, as an indicator for resource consumption, and Greenhouse gas emissions (global warming potential), as one of the most important environmental impacts, have been considered.

6.3.2.6 Primary Energy

Primary energy is energy contained in raw fuels and any other forms of energy that has not been subjected to any conversion or transformation process. Primary energies are transformed in energy conversion processes to more convenient forms of energy, such as electrical energy and cleaner fuels. The transformation includes losses that occur in the generation, transmission, and distribution of energy. For example, the provision of 1 MJ of electricity from natural gas requires 2.6 MJ of primary energy (GaBi 4.3). Primary energy consumption for “cradle to gate” or “cradle to site” is often referred to as “embodied energy”.

Embodied energy is the energy consumed by all processes from extraction of raw materials through to the production of a product. The definition of the system boundaries vary for different assessments and sometimes include the delivery to the building site, energy requirements for installation, and transport of workers to the site (“cradle to site”). However, data for these processes is often hard to quantify. Published figures for embodied energy are therefore often based on a “cradle to gate” concept.

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[3] Capital equipment does not need to be included in LCA studies of construction materials (Frischknecht et al. 2007).

For more information see:
http://www.greenhouse.gov.au/yourhome/technical/fs52.htm

Embodied energy usually includes energy from fossil fuels as well as energy from renewable fuels, based on the assumption that there is a limit on how much renewable energy can be harnessed. The supply of electricity from hydro or wind is for example restricted and should therefore also be used efficiently in order to replace as much fossil fuels as possible. In order to address this issue only harnessed renewable energy should be considered, e.g. electricity generated from hydro energy, or thermal energy from combustion of biomass. In this case, for example, the calorific value of biomass is included. Harnessed renewable energy is different from energy that is captured within a product, but not used for energy production, for example the solar energy required for the photosynthesis to grow timber.

In currently available commercial databases, including the widely used Ecoinvent database as well as the GaBi database non-harnessed solar energy for photosynthesis is also included. This is done to keep the energy balance intact because a calorific value is assigned to all timber products. This means there is an output of energy (calorific value of timber) and therefore an equivalent input of energy, i.e. solar, is required. However, this can be seen as distorting the overall use of renewable energy, because the solar energy for timber production can not be utilised in any other way. In the LCA data for building materials in New Zealand (Nebel et al. 2009) non-harnessed energy has therefore been excluded. However, as the NZ data does not cover all materials, it needs also to be consistent with available databases in order to be able to mix NZ with data from those to provide a full range of materials and this option has therefore been provided too. Not all materials used in the four buildings analysed in this report are available in the new New Zealand dataset, e.g. NZ specific LVL and Western Red Cedar data are not available and the data had therefore to be sourced from the GaBi database.

For the purpose of this project a sensitivity analysis has been done that compares the analysis of renewable plus non-renewable as well as only non-renewable embodied energy. For the timber products used from the GaBi database the solar contribution has been subtracted manually for the key timber products for this comparison, using the calorific value of the products. The results are indicative – because wood fibres are for example used in fibre cement and it was not possible to determine the accurate amount of all timber used in all processes. The results are shown in Figure 6.2 and indicate that the conclusions drawn from just the non-renewable proportion of the embodied energy are valid for the total embodied energy use (the results for the non-renewable energy follow an almost identical trend to the non-renewable & renewable energy combined). Therefore, the primary energy figures in this report will refer to the non-renewable proportion of primary energy only.

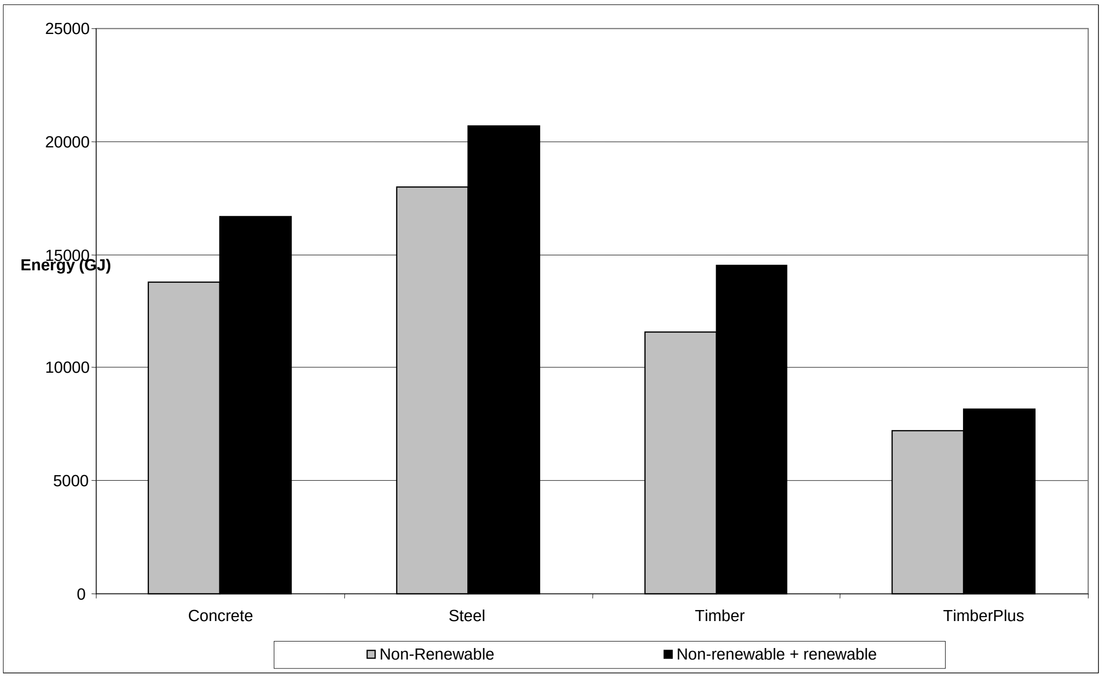

Figure 6.2: Comparison of embodied energy including renewable and non-renewable energy with only non-renewable energy for all materials

6.3.2.7 Global Warming Potential (GWP)

Increasing amounts of greenhouse gases (such as carbon dioxide and methane) enhance the natural greenhouse effect and are possibly leading to an increase in global temperature. During the 20th century, the average global temperature increased by about 0.6°C. Climate change is therefore often referred to as 'global warming'. Since the effects may also include storms or regional cooling, the term 'climate change' is more suitable. The natural greenhouse effect is an important factor in heating the atmosphere: short wavelength solar radiation entering the Earth's atmosphere is re-radiated from the Earth's surface in longer infrared wavelengths and then reabsorbed by components of the atmosphere. Without the natural greenhouse effect the average global temperature would be about -18°C. Due to the greenhouse effect the average global temperature is 15°C.

The general recommendation is to use the most recent figures for CO_2 equivalents for greenhouse gas emissions published by the Intergovernmental Panel for Climate Change (IPCC). In 2007, the IPCC updated its estimates of Global Warming Potentials (GWP) for key greenhouse gases from 1996.

The global warming potential is an expression of the contribution of a product or service to climate change. An internationally agreed characterisation model exists for the calculation of the Global Warming Potential. This has been published by the IPCC.

CO_2 has a weighting of 1 whereas the more potent greenhouse gas methane has a value of 25 kg CO_2 equivalents: in other words 1 kg of methane contributes 25 times as much to global warming as 1 kg CO_2 (over 100 years). This way it is possible to add up the results of all emissions which contribute to climate change.

6.3.3 Inventory Analysis

6.3.3.1 Material Quantities

The material quantities for each building type and building component are presented in tonnes in Appendix A. The material quantities, for each building type, were estimated by a quantity surveyor, Davis Langdon Shipston Davies in Christchurch. The total quantities, in tonnes, of the main building materials are summarised and presented in Table 6.1.

Table 6.1: Total building material quantities for each building design.

	Building type			
Material (tonnes)	**Concrete**	**Steel**	**Timber**	**TimberPlus**
Concrete – 17.5 MPA	61	62	53	53
Concrete – 40.0 MPA	679	2,170	1,316	1,316
Concrete – Pre-cast	4,595	101	N/A	N/A
Steel (NZ)	5.85	77.40	4.04	4.04
Steel (Aus)	17.66	265.64	5.55	5.55
Steel sheet	16.66	15.66	N/A	N/A
Reinforcing steel wire	114.41	24.03	19.48	19.48
Glass	47.03	47.03	47.03	31.94
Timber	11.57	10.94	61.28	130.82
Western Red Cedar	N/A	N/A	0.00	22.80
LVL	N/A	N/A	343.94	343.94
Plywood	4.09	4.09	54.45	64.79
MDF	2.00	2.00	2.00	70.62
Aluminium	6.63	6.63	6.63	1.06
Aluminium sheet mix	27.26	27.26	27.26	N/A
Plasterboard (Gypsum)	38.83	56.10	43.24	N/A
Paint	0.69	0.77	1.03	1.11
Fibreglass Insulation	3.30	8.34	7.93	8.42
Polystyrene Insulation	2.31	N/A	N/A	N/A
Fibre Cement	36.39	44.89	73.82	N/A

6.3.3.2 Maintenance

A maintenance schedule for each building design was developed based on a literature review of material lifetimes. Additional information, in particular with regard to the estimated lifetime of the timber products and components of the buildings, was provided in the report by Iain Nicholls, an Architectural Technologist at Warren and Mahoney in Christchurch (commissioned by the University of Canterbury as part of this overall research project). This report, *A Review of the timber used in four alternative designs of multi-storey buildings* is included in its entirety in Appendix F.

The replacement or refurbishment lifetimes of specific building materials are presented in Appendix B along with the references on which the figures are based.

Where the exact material is not given, the closest approximation is used. In some cases, more than one value is given for a single material, in which case the exemplar house figure (Szalay, 2006) is used, as this was calculated from many studies. For this study, it was assumed that the plywood panelling and MDF would have the same lifetime until replacement or refurbishment.

It was assumed that structural components and insulation would last the entire lifespan of the building of 60 years. It was also assumed that any replacements required, would be with an identical material to the original.

The replacement or refurbishment lifetime for acoustic ceiling tiles was estimated at 40 years and building components produced from Western Red Cedar were estimated to last 60+ years, except for windows which were assumed to last 40 years, provided there is strict adherence to a regular maintenance, such as staining (Nicholls, 2008).

6.3.3.3 End-of-Life Inventory

Base Scenario

The base scenario assumes that all building materials, including wood-based materials installed in each building, such as timber, LVL, plywood, and MDF, would be sent to landfill following deconstruction at the end of each building's life. For the landfill scenarios the transport to the landfill as well as all emissions to the operating the landfill (e.g. use of bull dozers) are included (GaBi, 2006).

The total mass of all the structural timber, architectural finishes and each wooden component for each building is presented in (Table 6.2). The carbon content of all wooden materials was assumed to be 50% (Wegener and Fengel, 1982; IPCC, 2006). The total carbon within the wooden materials sent to landfill was calculated for each building (i) based on this proportion (Table 6.2). Evidence has shown that 18% of carbon in wooden materials decomposes within 19-46 years following initial disposal but after this period no further significant amount of carbon is released (shown as Total carbon stored in landfill after 46 years (ii))(Ximenes, et al., 2008). In lines iii) and iv) respectively those figures have been converted into CO_2 equivalent storage.

From the proportion of carbon released, 50% of that will form into carbon dioxide (CO_2) and 50% into methane (CH_4) (IPCC, 2006). A 42 % capture of methane has been taken into account (MfE, 2009). It is anticipated that the amount of landfill gas captured from New Zealand landfills will increase in the future; however to avoid additional uncertainties, the latest figure based on physical data has been used. It was assumed that the captured methane was flared and thus converted to CO_2 for the calculations[4]. Another assumption was that 10% of the non-captured methane underwent microbial oxidation to CO_2 in the landfill (IPCC, 2006, Einola et al., 2009). Based on this information the total release of Greenhouse Gas (GHG) from decomposition was calculated. The total release of GHG from decomposition was then converted into respective GWP by multiplying each GHG by its GWP coefficient, CO_2 being 1 and CH_4, 25 (IPCC, 2007). The resultant GWP CO_2–equivalent (v) was then subtracted from the total CO_2 sequestered in the building (iii). This provided the net amount of CO_2–equivalent sequestered in landfill once decomposition has ceased (vi).

Due to its high GWP methane contributes around 76% to the total GWP of emissions from landfill.

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[4] Data on the amount of energy produced from landfill gas in New Zealand is available, however the uncertainties associated with attributing this to specific materials make this calculation very difficult. Although it can not be quantified at this stage, an additional benefit should be attributed to timber stored in landfills due the use of landfill gas for energy generation.

Table 6.2: Net tonnes CO_2 equivalent stored in landfill including total GHG emissions released from decomposition

		Building type			
		Concrete	Steel	Timber	Timber+
Timber	tonnes	11.57	10.94	61.28	164.96
LVL	tonnes	0.00	0.00	343.94	343.94
Plywood/MDF	tonnes	6.09	6.09	56.45	125.07
i) Total Carbon content of building	tonnes	8.83	8.52	230.84	316.99
ii) Total Carbon stored in landfill after 46 years	tonnes	7.24	6.98	189.28	259.93
iii) Total CO_2 sequestered in building	tonnes	32.38	31.22	846.40	1,162.28
iv) Total CO_2 sequestered in landfill after 46 years	tonnes	26.55	25.60	694.04	953.07
v) Total CO_2equivalent. released from decomposition (GWP)	tonnes	18.13	17.49	474.08	651.00
vi) Net CO_2e sequestered in landfill	tonnes	14.24	13.73	372.32	511.27

Figure 6.3 presents the results displayed in Table 6.2 graphically.

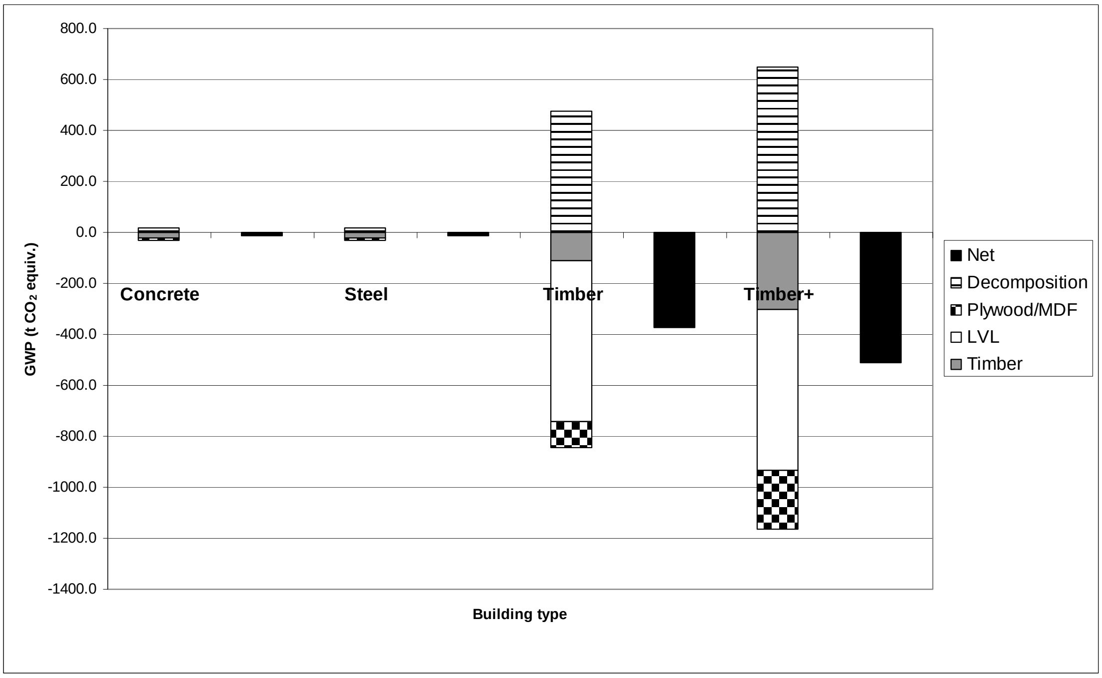

Figure 6.3: Tonnes CO_2 stored from timber components in landfill including total GHG emissions released from decomposition

Material Reutilisation Scenario

In the material reutilisation scenario, instead of sending waste materials to landfill, all wooden materials from all four building designs were used as a boiler fuel to provide energy and all structural steel and concrete was recycled.

In the steel recycling scenario, all recoverable structural steel (estimated to be 250 tonnes) was recycled. The amount of recycled steel was then assumed to replace virgin steel and credited to the building. For the Concrete building, the recoverable structural concrete (estimated at 2,180 tonnes) was assumed to be recycled to produce gravel. The production of the same amount of virgin gravel was then credited to the building.

The total mass of wooden materials was the same as in the landfilling scenario which includes timber, LVL, plywood, and MDF (see Table 6.3). It was assumed that all these materials would be burnt in a cogeneration plant with an efficiency of 60% (Connell Wagner, 2007; see also the Bioenergy Knowledge Centre calculator, www.bkc.co.nz/tools). This means that 60% of the calorific value of the wood (i) is recovered as useful energy (ii) through combustion with a ratio of electricity to heat of 1:3 (Connell Wagner, 2007). Thus 60% of the total calorific value of the timber was converted into electricity (iii) and heat (iv). It was assumed that this amount of electricity and heat replaces electricity from the national grid and heat from burning natural gas and therefore displaces fossil fuels (0.067 kg CO_2e per MJ heat from natural gas [a universal coefficient] and 0.078 kg CO_2 e per MJ electricity (GaBi 4.3, adjusted for electricity generation in the NZ grid) and primary energy (1.42 MJ per MJ heat from natural gas and 2.25 MJ per MJ electricity (GaBi 4.3)).

Table 6.3: Energy recovered from wood combustion and CO_2 displaced from avoiding the use of traditional energy sources (natural gas and electricity)

Building type	**Concrete**	**Steel**	**Timber**	**Timber+**
Material (t)				
Timber	11.57	10.94	61.28	164.96
LVL			343.94	343.94
Plywood/MDF	6.09	6.09	56.45	125.07
Total wood waste	17.66	17.03	461.67	633.97
Retained energy (GJ)				
(i) Calorific Value	276.91	267.03	7,238.99	9,940.65
(ii) at 60% efficiency	166.15	160.22	4,343.39	5,964.39
(iii) Metered Electricity	41.54	40.05	1085.85	1491.10
(iv) Metered Heat	124.61	120.16	3,257.54	4,473.29
CO_2e displacement (t)				
Electricity	3.23	3.12	84.45	115.97
Natural gas	8.31	8.01	217.17	298.22
Total	11.54	11.13	301.62	414.19
Primary energy displacement (GJ)				
Electricity	93.46	90.12	2,443.16	3,354.97
Natural gas	176.53	170.23	4,614.85	6,337.16
Total	269.99	260.35	7,058.01	9,692.13

This displacement can be explained more clearly by tracking the path of the carbon, within the wooden products, from cradle to grave.

Growing timber takes up CO_2 from the atmosphere and stores it as carbon. When the wood is harvested from the forest the carbon continues to be stored within the wood. The wood is then used in various forms in construction of buildings, exists over the full lifetime of the buildings and carbon continues to be stored up to the point of deconstruction.

When the deconstructed timber is combusted, CO_2 is released back into the atmosphere, which brings the balance back to zero. However, because beneficial energy is recovered at the same time, the need to use fossil fuels such as natural gas and electricity generated in coal, gas and oil fired power stations has been avoided. Therefore, the CO_2 that was not released, by avoiding the use of natural gas and electricity, can be subtracted from the GWP of the end-of-life phase in which the wood is being combusted.

The emission of CO_2 equivalents and the use of primary energy were then subtracted from the total life cycle results of each building respectively (Table 6.3), based on the above explanation. The use of natural gas for heat and the emissions related to producing electricity by burning of fossil fuel have been avoided.

6.3.3.4 Transport

It was assumed for all building materials that they would be sourced locally or from the closest possible supplier. All timber was assumed to be sourced locally (this is a fair assumption for most timber, excepting cedar, used in the TimberPlus building). For some materials that are available from multiple locations, such as concrete, aluminium, and paint, a New Zealand average distance was calculated.

It was assumed that structural steel would be imported from Australia. However, it would also be possible that steel would be imported from Asia.

The locations reflect a short distance (Auckland), a medium distance (Wellington) and a long distance scenario (Christchurch). The long distance scenario was chosen as the base scenario (as Christchurch is the actual location of the new Biological Sciences building used as a template in this study). Transport distances for the three scenarios are presented in Table 6.4.

Table 6.4 Distances travelled, via truck and ship, to deliver materials to building locations in Christchurch, Wellington and Auckland

	Christchurch (km)		Wellington (km)		Auckland (km)	
Material	**Truck**	**Ship**	**Truck**	**Ship**	**Truck**	**Ship**
Concrete	124		124		124	
Steel (NZ)	1,000	92	600		30	
Steel (Aus)	50	2,500	50	2,500	50	2,500
Glass	1,000	92	600		30	
Timber	427		400		200	
LVL	427		100		500	
Plywood/MDF	676	62	400		200	
Aluminium	400		400		400	
Plasterboard	20		600		30	
Paint	400		400		400	
Glass Insulation	1,000	92	600		30	
Poly Insulation	1,000	92	600		30	
Fibre Cement	1,000	92	600		30	

6.3.3.5 Operational Energy

Total Megawatt hours (MWh) consumed (electricity and natural gas) during the 60 year operation period for each building type was supplied by Nicolas Perez (Perez, 2008) (Table 6.5) as metered consumption. To demonstrate the total energy consumption this has been converted to primary energy and the respective GWP has also been calculated.

A life cycle inventory dataset for New Zealand has been used to calculate the primary energy content and the GWP for electricity. The dataset takes the New Zealand electricity mix as well as New Zealand specific emissions into account (MED, 2005). The dataset was developed in collaboration of Scion and PE-Europe and is based on generic datasets for the provision of electricity in GaBi Software 4.3 (GaBi, 2006).

The following results have been calculated:

Electricity:
Global Warming potential: 0.28 kg CO_2 equiv. / kWh
Primary energy: 8.1 MJ/kWh

The factors for heat from natural gas are based on datasets available in the GaBi 4.2 database.
Global Warming potential: 0.24 kg CO_2 equiv. / kWh
Primary energy: 5.1 MJ/kWh

The above results reflect the high proportion of renewable energy in the New Zealand electricity mix (66.6% in 2007 according to the Ministry for Economic Development)

The results for metered energy consumption, as well as primary energy and GWP are shown in Table 6.5. The figures for metered energy consumption have then been multiplied with the respective numbers for CO_2 equiv./kWh and MJ primary energy/kWh for heat from natural gas and electricity.

Table 6.5: Operational energy consumption (electricity and natural gas) over 60 years including metered MWh and Primary energy (GJ) consumption with associated GWP (t CO_2eq.)

Building type	Metered; Electricity (MWh) (Perez, 2008)	Primary energy x 8.1	CO_2 x 0.28	Metered; natural gas (MWh) (Perez, 2008)	Primary energy x 5.1	CO_2 x 0.24	Primary energy (GJ)	GWP (t. CO_2 eq.)
Concrete	14,470	117,207	4,052	3,346	17,065	803	135,863	4,910
Steel	14,760	119,556	4,133	3,382	17,248	812	138,428	5,000
Timber	15,446	125,113	4,325	3,236	16,504	777	143,315	5,161
Timber+	14,836	120,172	4,154	3,448	17,585	828	139,388	5,038

The primary energy consumption associated with the operation stage was determined and used instead of using the consumed MWh in the building because the system boundaries include all energy use associated with each stage of the life cycle. Therefore it was imperative to include all energy consumed in the process of delivering the useable energy to the buildings.

6.3.4 Impact Assessment

Total primary energy and GWP were the two impact categories calculated for each building type. The results for each building are presented for the following life cycle stages: initial material production and use, maintenance, transport, operation over the 60 year lifetime of the building/s and end-of-life.

The results are based on the Base scenario, as described in sections 6.3.4.1 to 6.3.4.3. The results for the reutilisation scenario and transport scenarios are presented in section 6.3.5.

6.3.4.1 Total Primary Energy Use and GWP

The total primary energy and GWP contributions from each building can be seen in Figure 6.4 and Figure 6.5 below. The Timber buildings have lower contributions to global warming than the Steel and Concrete buildings; the results for the Steel building are 30% higher than for the TimberPlus building. The TimberPlus building has the lowest primary energy use over its life cycle, followed by Concrete, Timber and Steel respectively. The total primary energy use for the Steel building is 7 % higher than the TimberPlus building.

The main contribution to each impact category is during the building's operational phase, in all buildings contributing over 85% of the primary energy use and over 70% of the GWP impacts. The difference between each building's transport, maintenance, and end-of-life make relatively little difference but the differences in initial embodied energy are significant. In Table 6.6 and Table 6.7, the total figures for each stage of the life cycle are presented.

When breaking down the total impact of the buildings into life cycle stages, it can be seen that the operational energy is the largest figure. It makes up 87% (Steel) to 94% (TimberPlus) of the total energy use of the buildings, and 72% (Concrete) to 78% (TimberPlus) of the total emissions that contribute to GWP. Embodied energy makes up 5% (TimberPlus) to 11% (Steel) of the total primary energy use and embodied GWP makes up 9% (TimberPlus) to 23% (Steel) of the impact from greenhouse gas emissions. Maintenance is the only other significant contributor in each category. End-of-life (transport of materials to landfill and the landfilling process as well as storage of carbon and potential release of methane) is around 0.5% for primary energy use and ranges from 2% (Concrete) to -9% (TimberPlus) for the GWP. Transport of materials to site makes up around 0.3% of primary energy use and 0.5% of GWP.

The differences in the buildings' embodied energies and embodied global warming potentials can be seen below (in Table 6.6 and Table 6.7). The Steel building has the highest values for both categories, followed by Concrete, Timber and TimberPlus. However, taking into account the full life cycle (including operation energy) the order for the energy use is different. Due to increased operational energy, the total primary energy use for the Timber building becomes greater than for the Concrete building. The order of the total GWP values remains the same. This point has been expanded in the inventory section (6.3.3.3).

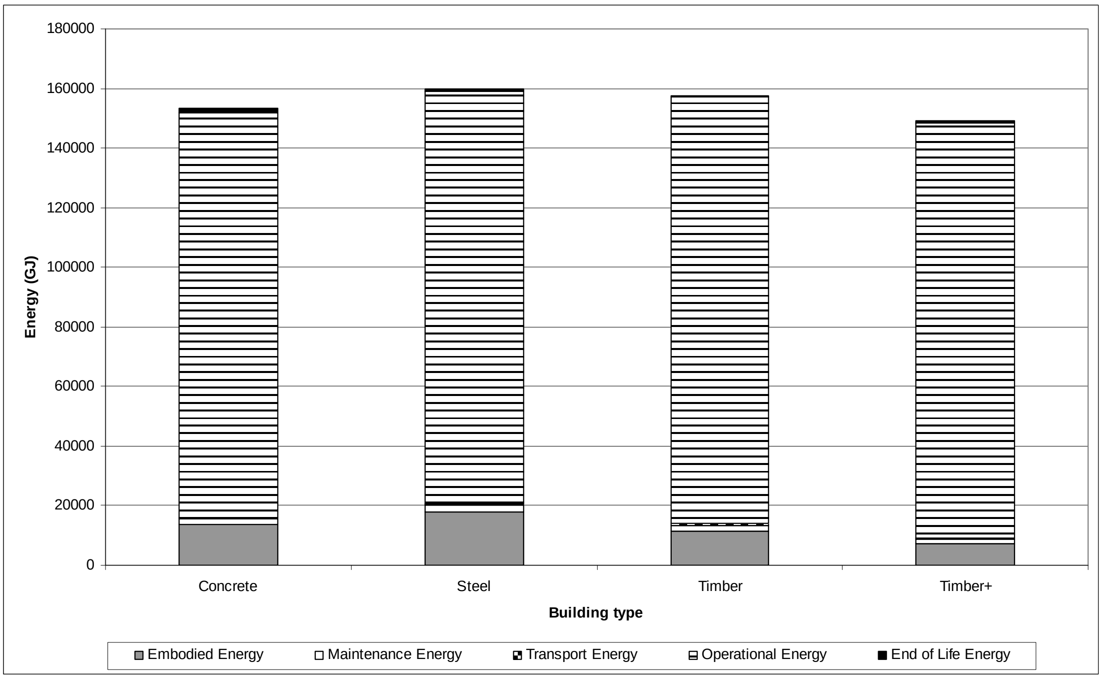

Figure 6.4: Primary energy consumption for each stage of the life cycle for all four buildings

Table 6.6: Total amount of energy consumed (GJ) in each stage of the life cycle for all building types

Building type	Initial embodied energy (GJ)	Maintenance energy (GJ)	Transport energy (GJ)	Operational energy (GJ)	End-of-life energy (GJ)[5]	TOTAL ENERGY (GJ)
Concrete	13,772	1,722	589	135,863	1,342	153,288
Steel	17,970	2,201	532	138,428	691	159,822
Timber	11,597	1,887	408	143,315	490	157,696
TimberPlus	7,191	1,518	419	139,388	492	149,008

Table 6.7: Total GWP for each stage of the life cycle of all building types

Building type	Initial embodied [t CO2 equiv.]	Maintenance [t CO2 equiv.]	Transport [t CO2 equiv.]	Operation [t CO2 equiv.]	End-of-life [t CO2 equiv.][6]	CO2 storage [t CO2 equiv.][7]	TOTAL [t CO2 equiv.]
Concrete	1,576	131	42	4,910	168	-32	6,794
Steel	1,615	166	39	5,000	95	-31	6,883
Timber	971	139	29	5,161	529	-846	5,982
Timber+	566	99	30	5,038	706	-1,162	5,276

[5] End-of-life refers to the energy associated with the disposal of a material, which may be positive or negative depending on the disposal method.
[6] In this landfill scenario, end-of-life includes transport of materials to the landfill and subsequent emissions from the landfill.
[7] The calculation of initial embodied GWP does not include carbon sequestered in the building materials. The potential carbon stored in the materials is detailed in Table 6.2.

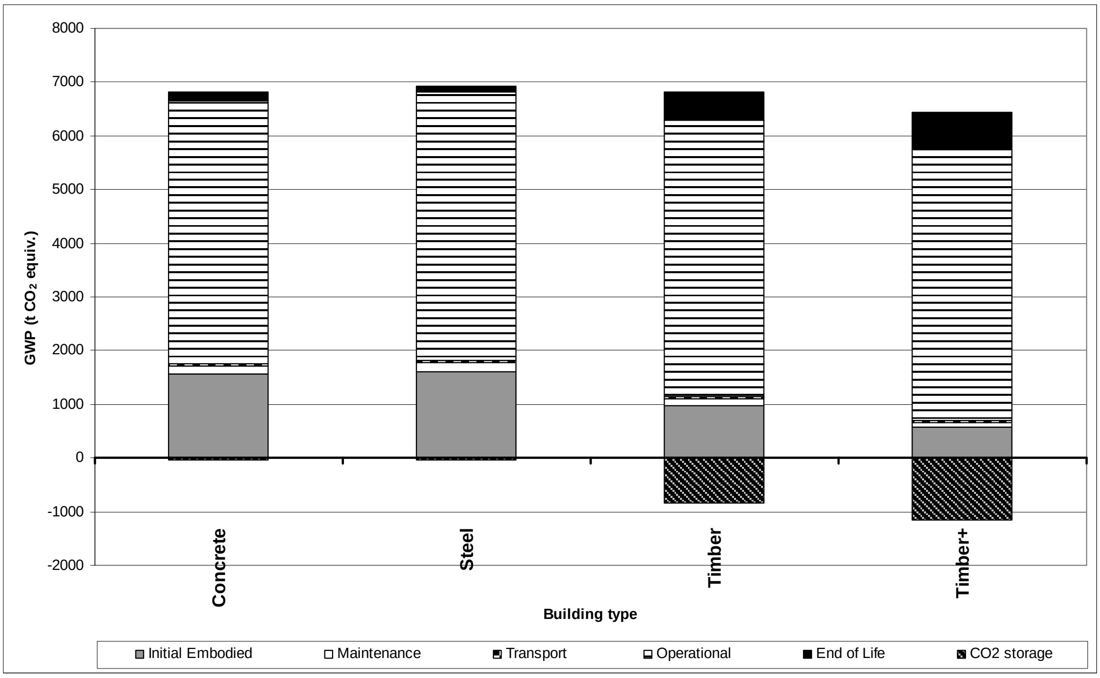

Figure 6.5: GWP (tonnes CO_2 equivalent) for each stage of the life cycle of all the building types

6.3.4.2 Contribution of building components

In this section, embodied energy (as distinct from total primary energy) and embodied GHG emissions are analysed (cradle to gate only). However, it should be noted that the calorific value, as well as, the stored carbon (that is potential sequestration in the timber) are not taken into account. These factors are dependent on the end-of-life scenario of the building and are taken into account in the full life cycle assessments. Especially, the carbon storage should only be considered if the whole life cycle is taken into account because the effect of different end-of-life scenarios can influence this result significantly, as shown later in section 6.3.5. However, Figure 6.3 has shown that the carbon storage in landfill that can be attributed to specific materials can be significant, if a landfill scenario is assumed. Refer to section 6.3.3.3 on the details how this was calculated.

The highest individual energy user is the structure of the Steel building (Figure 6.6). Aluminium louvres are the largest energy input for the Concrete and Timber buildings, and the second largest of the Steel building. The TimberPlus building uses wooden louvres, which are almost 20 times lower in energy than the aluminium louvres used in the other buildings. Window type also makes a significant contribution to embodied energy and again, the reason the TimberPlus building has a lower figure than the others is because it uses wooden frames instead of aluminium. Suspended floors are the next significant embodied energy contributor, and this is primarily from Concrete and Steel. The values are much higher than for the foundations figures, because much more concrete and steel is used in five suspended floors.

The higher value for the ceiling of the TimberPlus building can be attributed to the large quantities of MDF used in the ceilings.

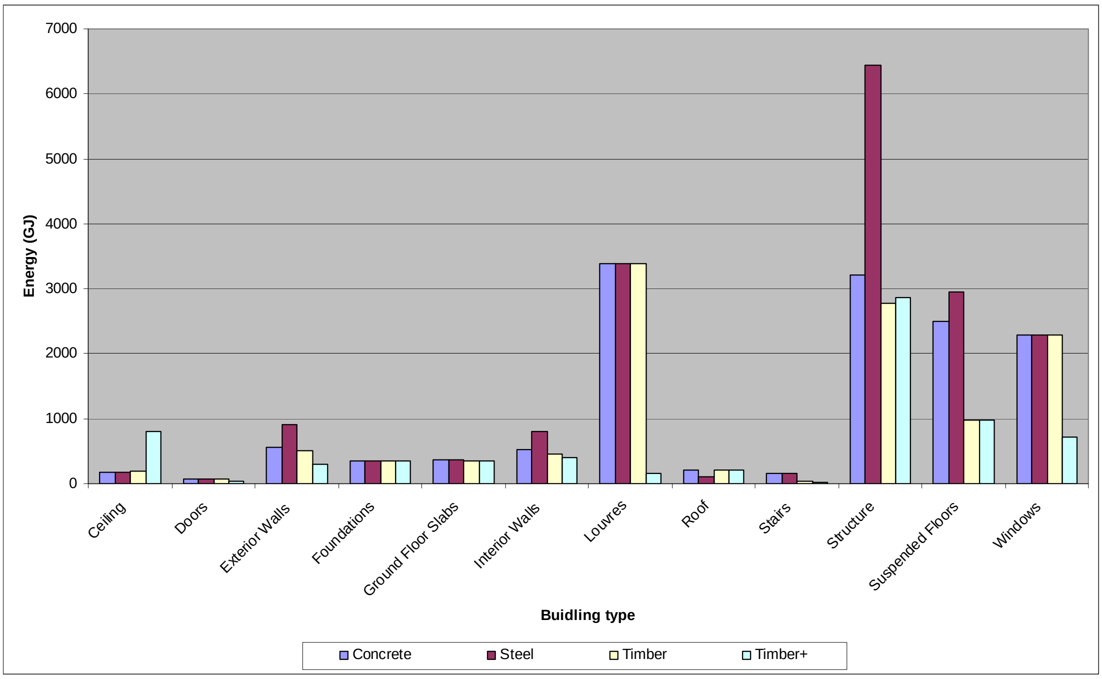

Figure 6.6: Total embodied energy (GJ) for each building component, compared between building types

The global warming potential of the building components is shown in Figure 6.7, and it can be seen that the values in general follow the same trends as the embodied energy graph (Figure 6.6). Again the three largest contributors are the suspended floors and structure of the Concrete and Steel buildings, and the aluminium louvres on all buildings except the TimberPlus building.

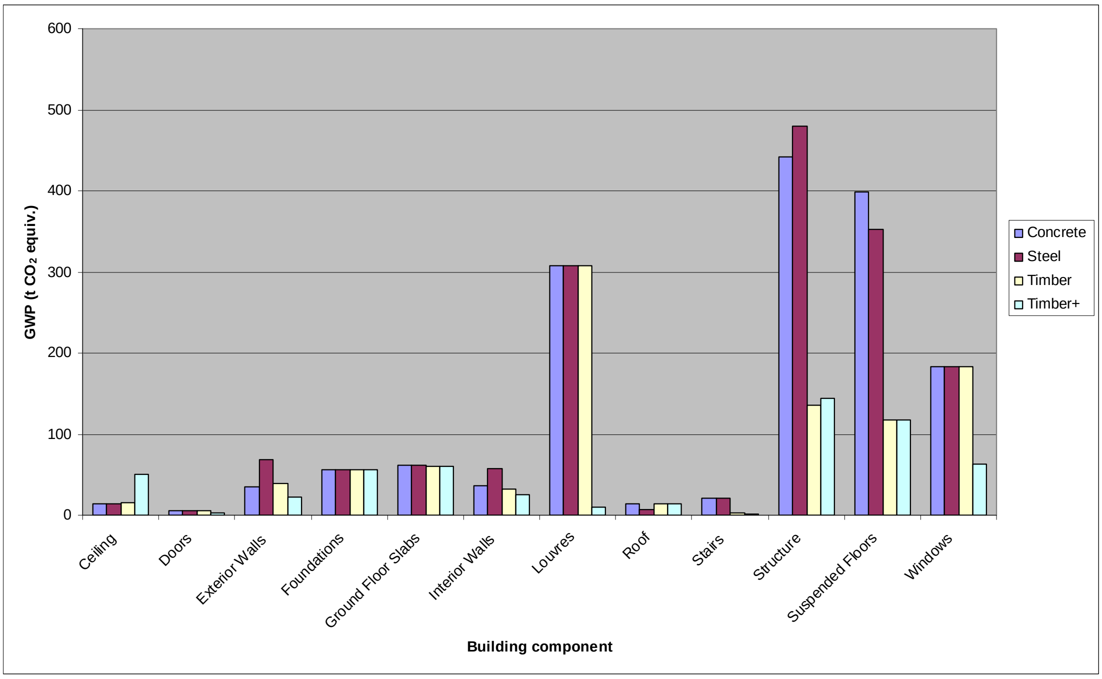

Figure 6.7: GWP (tonnes CO_2 equivalent) estimated for each building component, compared between building types

Figure 6.6 and Figure 6.7 show clearly that the primary energy consumption and the global warming potential of the structure of the Steel and Concrete buildings are higher than for the structures of the Timber buildings.

As explained above, carbon storage is not shown in Figure 6.7 due to the uncertainties existing around different end-of-life scenarios. However, as shown in Figure 6.3, the carbon storage can be significant even if a proportion of methane emissions are assumed in a landfill scenario.

6.3.4.3 Maintenance related embodied energy

When looking at impacts of building maintenance, the categories that stand out are where the impact is zero (Figure 6.8 and Figure 6.9). No repairs or replacements are required in the foundations, ground floor slabs, structure (including insulation) and suspended floors. The highest impact in both embodied energy and GWP is from replacement of windows, with the exception of the TimberPlus building. The bulk of energy used in window production can be attributed to aluminium frames. The TimberPlus building again has the lowest impact here, due to use of wooden frames as opposed to aluminium.

The interior walls and ceilings of the TimberPlus building have a relatively high impact compared to the other buildings. This is because of the higher embodied energy in the MDF panels compared to the building materials used for the other building designs. Assuming the same ceiling as in the Concrete, Steel and Timber building for the TimberPlus building, the total GWP for this building could be reduced by about 50 tonnes of CO_2 equivalents.

Interestingly, the Concrete building has the lowest exterior maintenance, as the concrete structure only has to be painted (wooden tiles and steel tiles must be replaced to some extent on the other building designs). TimberPlus is the only building with maintenance related energy for louvres; the louvres are wooden (cedar) and are expected to last the full 60 year lifespan of the building but durability is dependent on routine and regular maintenance through the application of stain.

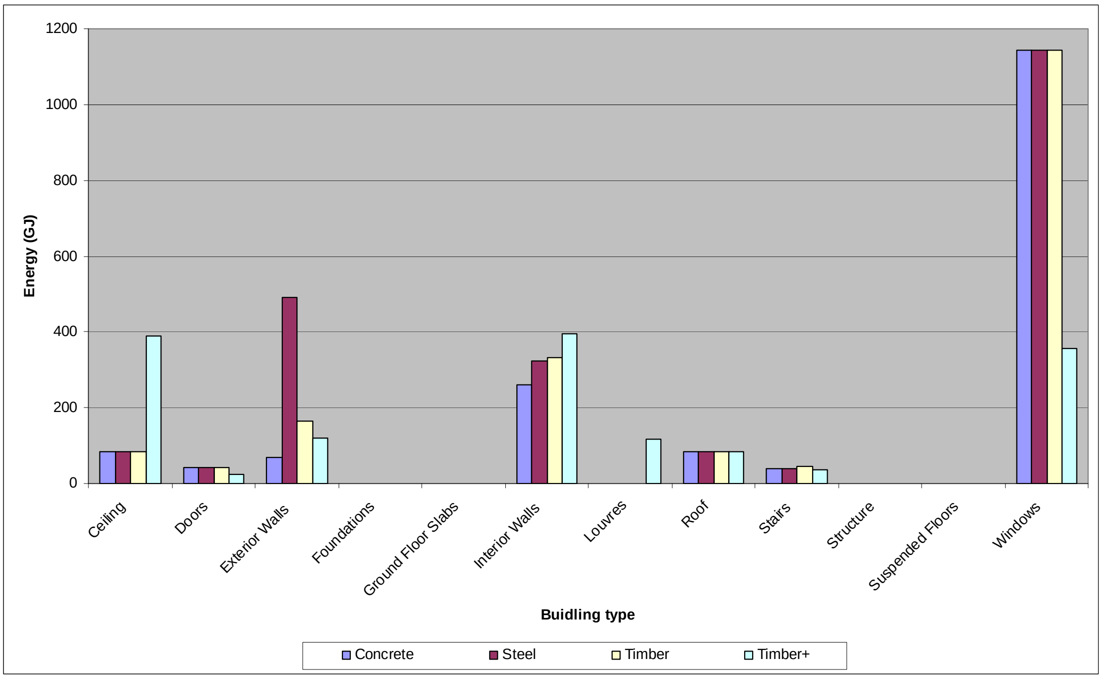

Figure 6.8: Total embodied energy (GJ) for each maintained building component, compared between building types

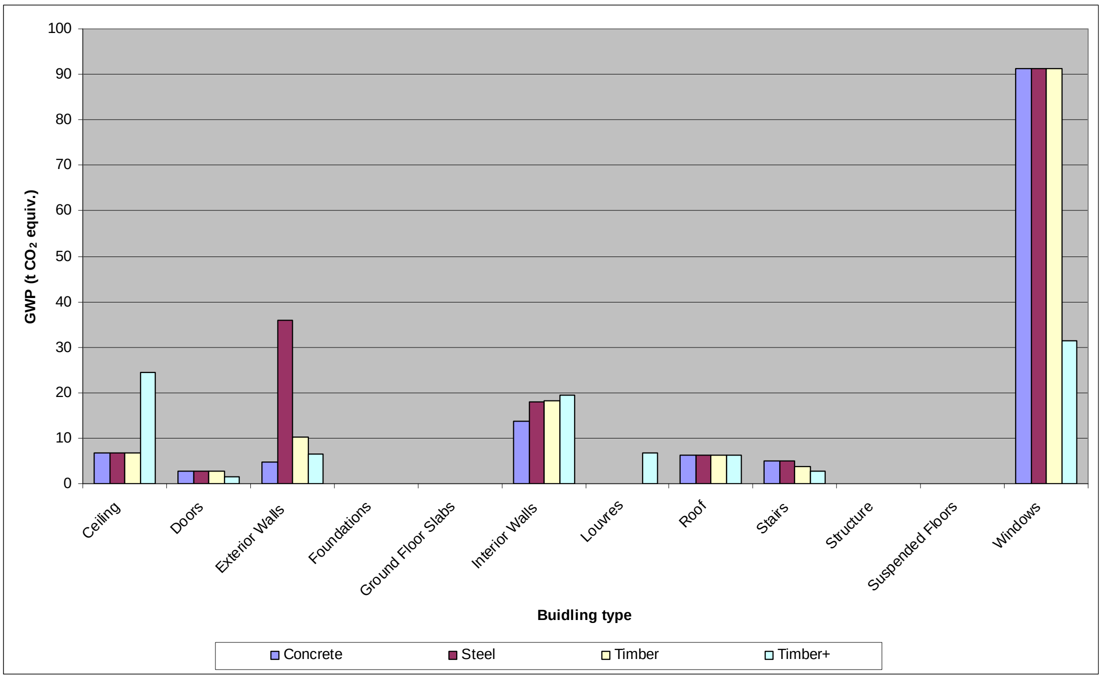

Figure 6.9: GWP (tonnes CO_2 equivalent) estimated for each maintained building component, compared between building types

The TimberPlus building has the greatest impacts (embodied energy and GWP) for maintenance for three of the building components (interior walls, ceilings, and louvres). Despite this it still has the lowest total impact (Figure 6.10 and Figure 6.11). This is partly due to the lower embodied energy of the wooden window frames, compared with the aluminium window frames used in the other buildings. It is worth noting that the impacts from the Steel and Timber buildings from maintenance are very similar because both buildings have the same materials for interior walls, ceiling, and window frames. If the same ceiling is assumed for all four buildings, the maintenance related GWP for the TimberPlus building would reduced by approximately 25 tonnes of CO_2 equivalents.

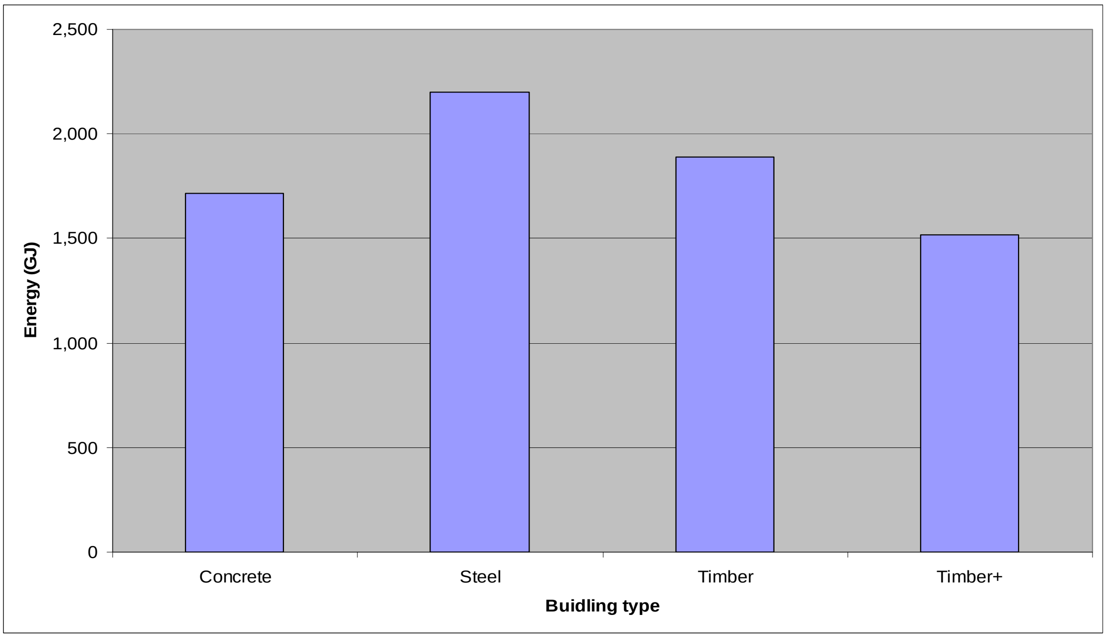

Figure 6.10: Total embodied energy (GJ) of all the materials required for maintenance and refurbishment, compared between building types

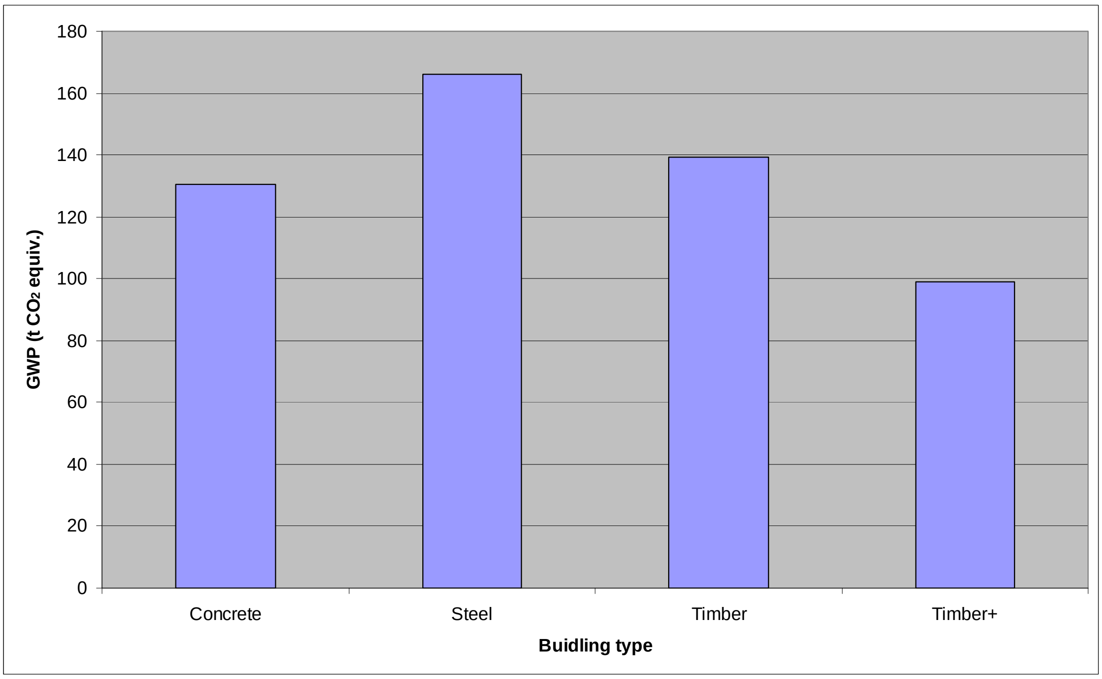

Figure 6.11: Total GWP (tonnes CO_2 equivalent) for all the materials required for maintenance, compared between building types

6.3.5 Scenarios

6.3.5.1 Landfill vs. Material Reutilisation

Two end-of-life scenarios were proposed for construction and demolition waste. The Base scenario assumes that all waste materials are landfilled. As described in the inventory analysis (section 6.3.3.3) a percentage of the timber in landfill is assumed to decompose and the rest will store carbon for some time, effectively forming a carbon reservoir. The second “reutilisation scenario” involves using the wood waste for energy, which releases the stored CO_2, but at the same time displaces energy and the related emissions from other sources. See section 6.3.3.3 for a description of the processes. All structural concrete and steel was recycled in the reutilisation scenario.

The difference in the total primary life cycle energy consumption and GWP of both scenarios is presented in Table 6.8 and Table 6.9, as well as Figure 6.12 and Figure 6.13.

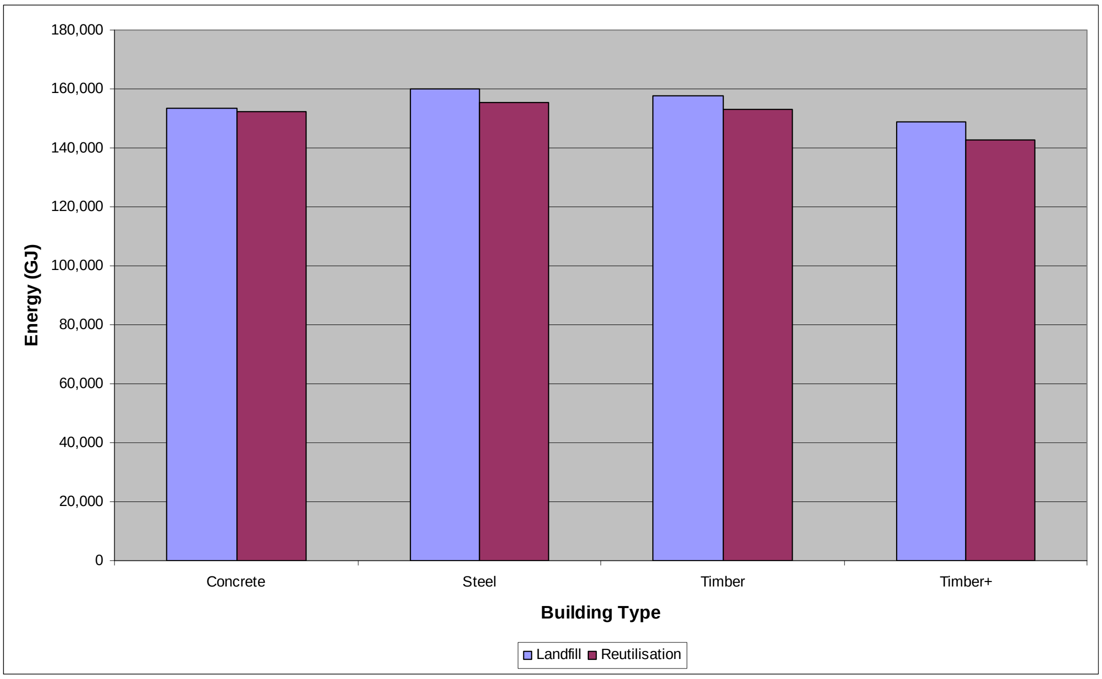

Figure 6.12: Comparison between total primary energy use of landfilling and reutilisation scenarios

Table 6.8: Total primary energy consumption of each building's life cycle for landfilling and reutilisation scenarios

Building type	Landfilling [GJ]	Reutilisation [GJ]
Concrete	153,288	152,464
Steel	159,822	155,306
Timber	157,696	153,022
Timber +	149,008	142,713

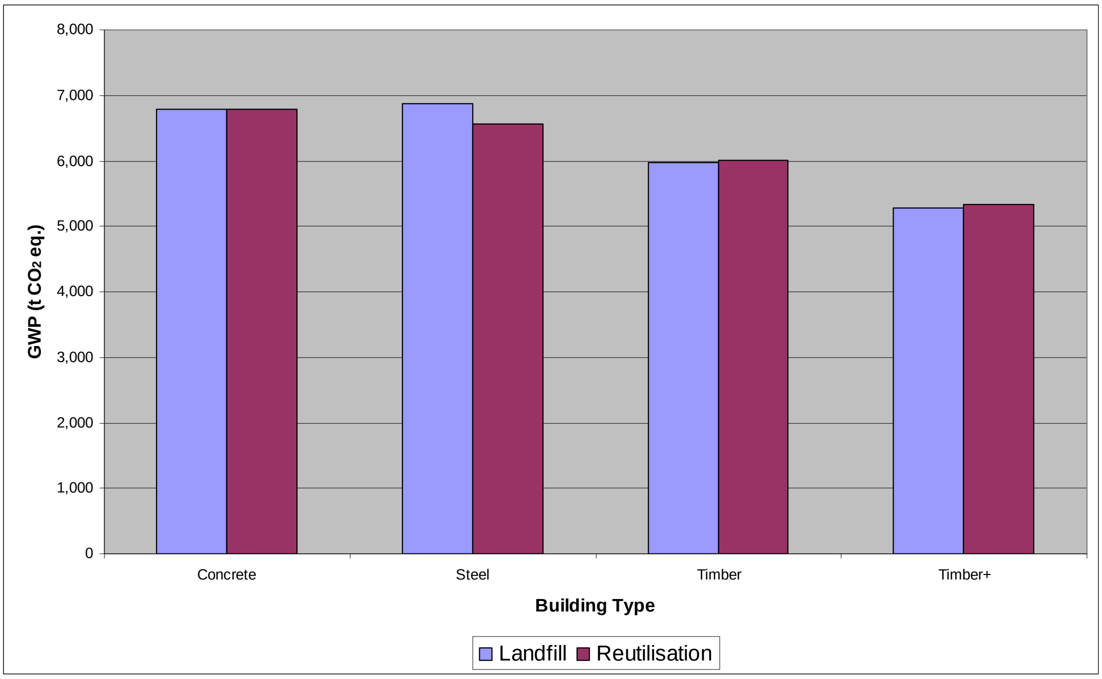

Figure 6.13: Comparison between total GWP (tonnes CO_2 equivalent) of landfilling and reutilisation scenarios

Table 6.9: Total GWP of each building's life cycle for landfilling and reutilisation scenarios

Building type	Landfilling [t CO_2eq.]	Reutilisation [t CO_2eq.]
Concrete	6,794	6,782
Steel	6,883	6,567
Timber	5,982	6,010
Timber +	5,276	5,330

The total primary energy use of all four buildings was lower in the reutilisation scenarios, as some energy was generated from wooden materials. It should again be noted that the landfill results could change in the future if landfill gas capture rates increase, and if energy from landfill gas is able to be calculated. The GWP results are more varied than the energy use results. As with energy, the GWP impacts of the Steel and Concrete buildings are reduced when material reutilisation is chosen as an end of life option. However, for the Timber and TimberPlus buildings the results indicate that the benefit as a result of carbon storage in landfills (landfill scenario) is very slightly greater than the benefit from offsetting emissions from other energy sources (reutilisation scenario).

The small difference in both primary energy use and GWP for the Concrete building is because concrete is recycled into aggregate which is a very low embodied energy product. The reason that the Steel building fares much better in the reutilisation scenario can be attributed largely to the recycling of steel (avoiding some primary steel, which has a very high embodied energy).

The Concrete building has the lowest difference in energy and GWP between the two scenarios, with the reutilisation scenario showing a 0.5% and 0.2% saving respectively. The TimberPlus building has the greatest energy saving in the reutilisation scenario, with a 4.2% reduction, because it has a large quantity of wood waste for combustion. The Steel building has the greatest reduction in GWP, with a 4.6% reduction; again this is due to the high embodied energy of steel, which is recycled into other steel products, thus avoiding production of a large quantity of virgin steel. The reutilisation scenario for all buildings shows a reduction in total energy, as the energy recovery from combusting the wood has been subtracted from the total energy use of the buildings.

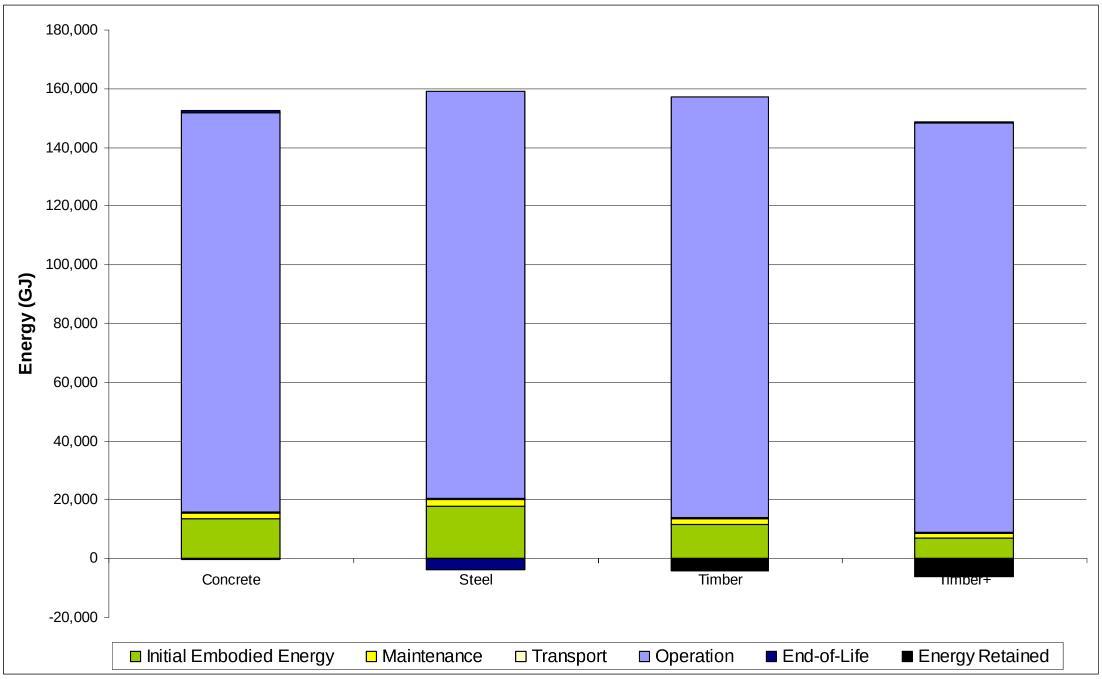

Figure 6.14: Energy consumed in each stage of the life cycle, compared between building types in the reutilisation scenario

Table 6.10: Total primary energy consumption of each stage of the life cycle including the total energy recovered through combustion and avoided energy due to recycling

Building type	Initial embodied [GJ]	Maintenance [GJ]	Transport [GJ]	Operation [GJ]	End-of-life [GJ][89]	Energy retained [GJ][10]	Total [GJ]
Concrete	13,772	1,722	589	135,863	684	-166	152,464
Steel	17,970	2,201	532	138,428	-3,665	-160	155,306
Timber	11,597	1,887	408	143,315	159	-4,343	153,022
Timber +	7,191	1,518	419	139,388	161	-5,964	142,713

[8] End-of-life in this recycling scenario includes the recycling of recoverable concrete to make into more aggregate (but still utilising significant amounts of primary energy) and recoverable steel (a negative value because the energy difference between making recycled steel and virgin steel is enormous and in this case the recycled steel replaces some the production of some virgin steel).
[9] Note that only large amounts of recyclable material are accounted for; so, for instance, there is no account taken of recycling of foundation concrete in the Timber building.
[10] Energy retained refers to the total potential energy that could be produced from combustion of materials.

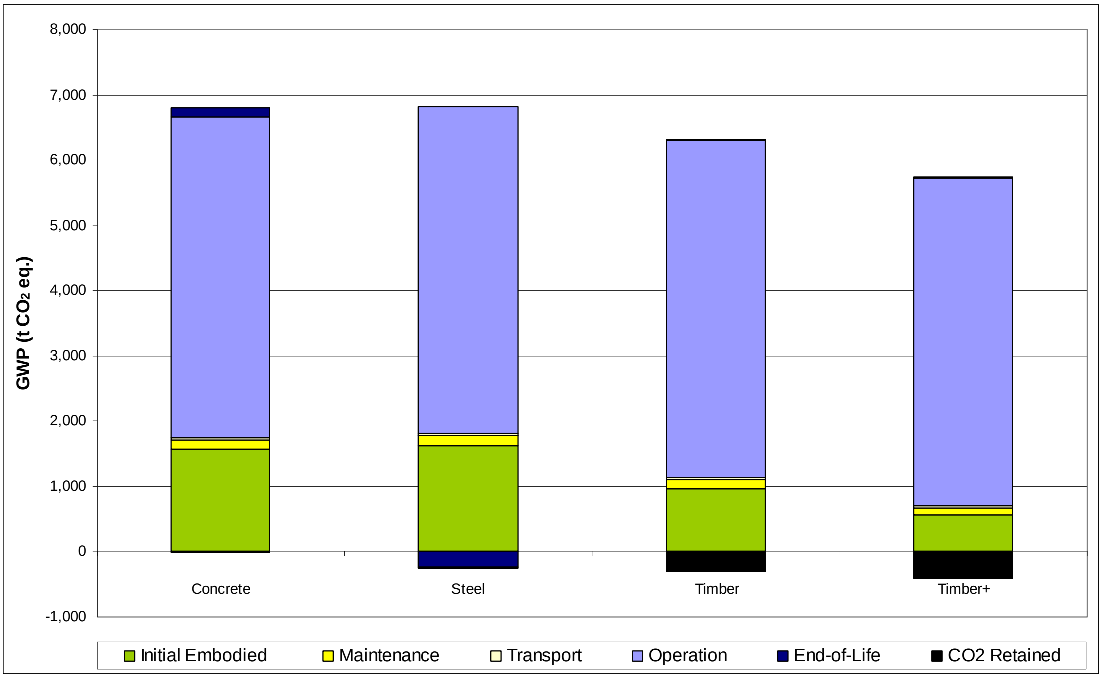

Figure 6.15: GWP of each unit process, compared between building types in the reutilisation scenario.

Table 6.11: Total GWP (tonnes CO_2 equivalent) of each stage of the life cycle including the CO_2 retained through displacing the use of traditional energy sources

Building type	Initial embodied [t CO_2eq.]	Maintenance [t CO_2 eq.]	Transport [t CO_2 eq.]	Operation [t CO_2 eq.]	End-of-life [t CO_2 eq.]	CO_2 eq retained [t CO_2eq .]	Total [t CO_2 eq.]
Concrete	1,576	131	42	4,910	135	-12	6,782
Steel	1,615	166	39	5,000	-241	-11	6,567
Timber	971	139	29	5,161	11	-302	6,010
Timber +	566	99	30	5,038	12	-414	5,330

The total primary energy consumed and GWP of each stage of the life cycle for the reutilisation scenario are presented in Table 6.10 and Table 6.11 respectively (presented graphically in Figure 6.14 and Figure 6.15). The negative figure in the End-of-life column for Steel includes a credit for the displacement of virgin steel. These tables also present the quantity of energy recovered from combusting the wood components and the CO_2 retained through displacing the use of traditional energy sources with their associated CO_2 emissions. These figures can be seen in the 'Energy retained' (Table 6.10) and 'CO_2eq.retained' (Table 6.11) columns, and the larger figures represent the larger quantities of wood available for energy recovery in the Timber and TimberPlus buildings.

6.3.5.2 Transport Distances

It is important to note that the transport contribution to total impact is minimal at around 0.3% and 0.5% for primary energy use and GWP respectively. However, for the purpose of the study it was interesting to test the relevance of the assumptions made. A sensitivity test was therefore carried out to test the difference in environmental impact when the location of each type of building was changed (Base scenario assumed Christchurch). The change in location means that transport distances for materials would be different depending on the location of the building. In the transport scenarios, the buildings were located in Christchurch, Wellington, and Auckland. Table 6.4 presents the material transport distances to supply materials to these locations. It was assumed that materials would be sourced from the closest possible supplier.

Changing the location of the building made significant difference to the primary energy use and GWP for the life cycle stage “transport” for each building type. A significant reduction in both impact categories was seen when the building was relocated to Auckland. This is because many building materials are produced in Auckland therefore requiring less transport. Christchurch had the highest impact for all the building types because it was assumed that the majority of building materials were transported from Auckland. This might not reflect the reality – but for the purpose of the modelling a “short distance, medium distance and long distance” scenario was required - Christchurch was therefore chosen to reflect the “long distance” scenario. This meant that the “worst case” would be used in the base scenario – yet transport still only contributed around 0.5 %.

There was an overall reduction in transport related energy consumption of 30% for the Concrete building between Christchurch and Auckland.

Taking into account that transport contributed only around 0.5 % to the overall life cycle impacts for the base scenario (the “long distance scenario”), the variation between locations can be seen as insignificant even though it appears that there are significant impact differences between building locations. These changes can be seen graphically on the next page in Figure 6.16 and Figure 6.17.

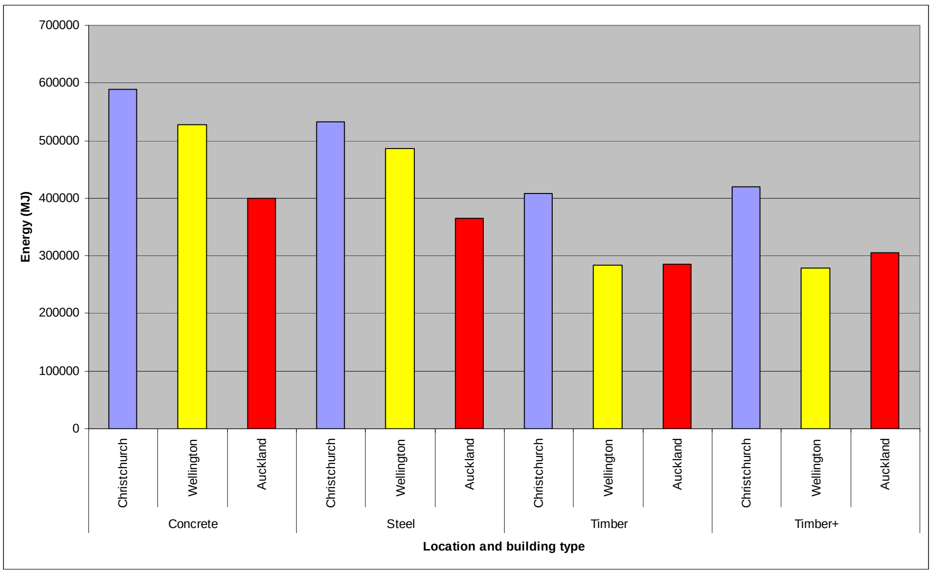

Figure 6.16: Comparison of total energy (GJ) consumed from transporting materials to sites in Christchurch, Wellington and Auckland, for all building types

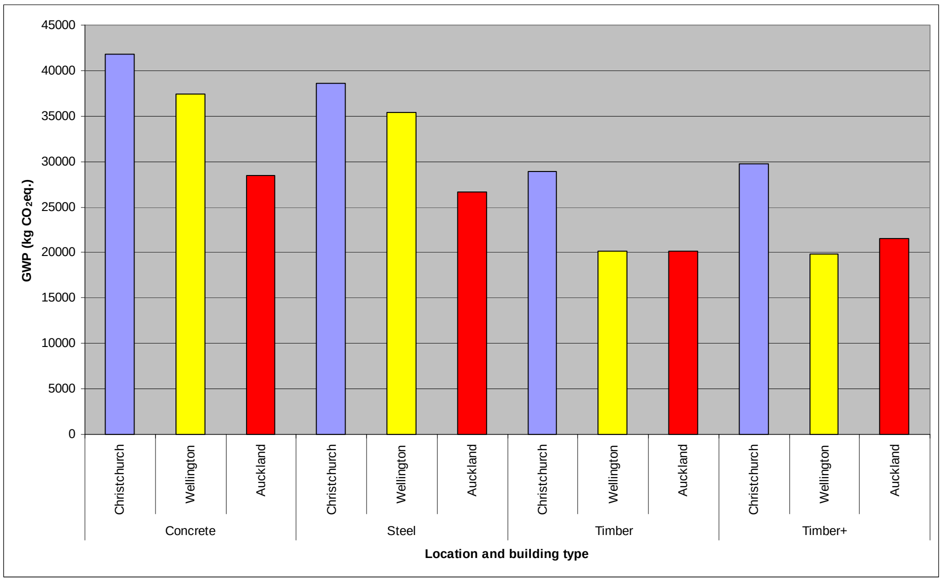

Figure 6.17: Comparison of total GWP (tonnes CO_2 equivalent) from transporting materials to sites in Christchurch, Wellington and Auckland, for all building types

6.4 Green Star Assessment and Comparison

6.4.1 Approach

The Green Star environmental rating system was introduced in New Zealand in 2007. Although there are some conceptual difference between LCA methodology and Green Star, both tools aim to identify life cycle impacts and have the potential to minimise the environmental impacts of buildings. Both tools have in common that they take energy use and materials in to account. However, the approach of both tools is conceptually different. Whereas the LCA is based on quantified data of all materials and energy used over the life time of a building, Green Star is based on credits for a number of criteria.

The aim of this section is to compare the results of both tools, based on the same assumptions. A brief introduction to the Green Star tool is provided as background information.

The assumptions for the LCA study described in this report are the basis for the comparison.

6.4.2 Introduction to Green Star

The Green Star environmental rating system was developed by the New Zealand Green Building Council (NZGBC) with the aim to:

- define green building by establishing a common language and standard of measurement;
- promote integrated, whole-building design;
- identify building life-cycle impacts;
- raise awareness of green building benefits;
- recognise and reward environmental leadership; and
- transform the built environment to reduce the environmental impact of development.

The Green Star NZ office design v 1.2 tool was developed for the design stage of office buildings to evaluate the environmental initiatives and/or potential environmental impacts of commercial office base building designs.

In Green Star, credits are awarded for certain activities. For example 1 point is awarded where it can be demonstrated that the percentage of all steel in the design has a post-consumer recycled content great than 60 % by mass, and 2 points for 90 % by mass. If the material cost of steel represents less than 1 % of the project's total contract value then this credit would be *"not applicable"*. Similarly 2 points are awarded where it is demonstrated that all timber and composite timber products are either post-consumer re-used timber or FSC certified timber or a combination thereof. In other categories points are awarded for land use, IEQ, transport etc (Figure 6.18).

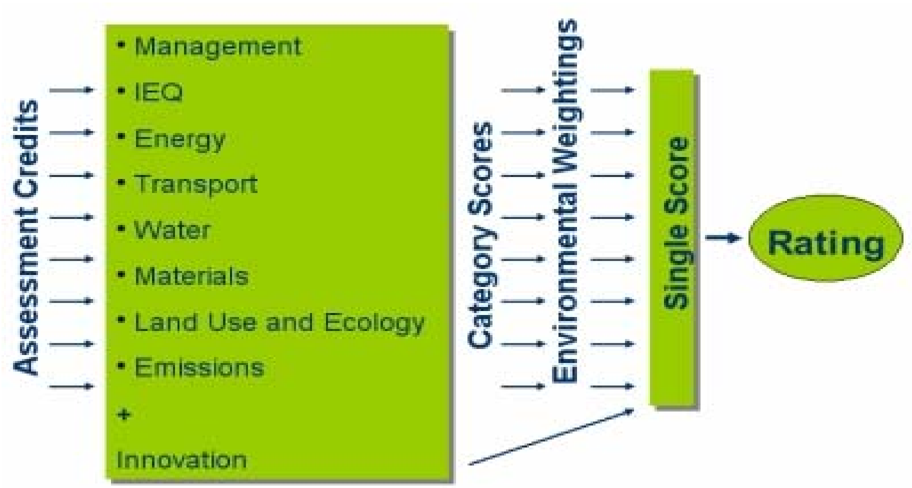

Figure 6.18: Green Star methodology (NZGBC 2008)

All points are then weighted and summarised into a single score, where materials have a contribution of 10 % to the total score whereas energy has a contribution of 25 %. For all weightings see Table 6.12.

Table 6.12: Weightings in Green Star tool

Management	10 %
Indoor Environmental Quality	20 %
Energy	25 %
Transport	10 %
Water	10 %
Materials	10 %
Land Use and Ecology	10 %
Emissions	5 %
	100 %

6.4.3 Research Approach for Comparison

Due to the differences in the scope of both tools, the comparison was restricted to those aspects which are taken into account in both tools, i.e. material use and energy use. All features of the buildings that are not strictly material or energy use related were therefore assumed to be identical for the four different building designs - Concrete, Steel, Timber and TimberPlus.

Two scenarios were assessed in Green Star. A base scenario which took into account the dominant 'core' materials only, i.e. timber, steel and concrete only and a recycling scenario which is similar to the reutilisation scenario in the LCA study. Both Green Star scenarios are shown in Table 6.13. The justification for the credits is explained in section 6.4.3.1 for the Green Star base scenario and in section 6.4.3.2 for the Green Star recycling scenario.

6.4.3.1 Green Star Base Scenario

The Green Star Base scenario took only the core materials of each building type into account, i.e. no points for concrete or steel were awarded in the Timber building. Otherwise the Timber building would score credits for either steel or concrete whereas the intention was to analyse the credits awarded for the core materials of each building option only.

Timber building

- Not applicable (N/A) was ticked for recycled steel content and concrete content respectively although, according to the Green Star methodology N/A can only be ticked if the material cost for steel or concrete respectively is less than 1 % of the project's total contract value.
- Sustainable timber (FSC certified) was chosen for the timber option of the building.
- Operational energy figure specific to the Timber building were included (73 kWh/m^2/yr metered electricity and 15 kWh/m^2/yr metered natural gas).
- All other assumptions were identical to the Timber, Steel and Concrete building.

TimberPlus building

- The amount of timber used cannot be accounted for in Green Star. The results for the TimberPlus building were therefore identical with the Timber building.
- Operational energy figures specific to the TimberPlus building were included (70 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered natural gas).
- All other assumptions were identical to the TimberPlus, Steel and Concrete building.

Concrete building

- Recycled concrete was assumed for the Concrete building. The N/A option was ticked for Steel and Timber respectively.
- Operational energy figure specific to the Concrete building were included (68 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered natural gas).
- All other assumptions were the same as for Steel and Timber.

Steel building

- Recycled steel was assumed for the Steel building. The N/A option was ticked for Concrete and Timber respectively.
- Operational energy figure specific to the Steel building were included (70 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered natural gas).
- All other assumptions were the same as for Concrete and Timber.

Table 6.13: Overview of Green Star input.

Building	Green Star category	Green Star Base	Green Star Recycling
Timber Building	Concrete	Not applicable	Concrete recycling (mass contribution > 1%)
	Steel	Not applicable	Not applicable (mass contribution < 1 %)
	Timber	Sustainable timber	Sustainable timber
	Operational energy	73 kWh/m^2/yr metered electricity and 15 kWh/m^2/yr metered nat. gas	73 kWh/m^2/yr metered electricity and 15 kWh/m^2/yr metered nat. gas
	Other material categories	Identical assumptions for all four buildings	Identical assumptions for all four buildings
TimberPlus Building	Concrete	Not applicable	Concrete recycling (mass contribution > 1%)
	Steel	Not applicable	Not applicable (mass contribution < 1 %)
	Timber	Sustainable timber	Sustainable timber
	Operational energy	70 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered nat. gas	70 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered nat. gas
	Other material categories	Identical assumptions for all four buildings	Identical assumptions for all four buildings
Concrete building	Concrete	Recycled concrete	Recycled concrete
	Steel	Not applicable	Not Applicable
	Timber	Not applicable	Sustainable timber
	Operational energy	68 kWh/m2/yr metered electricity 16 kWh/m2/yr metered nat. gas	68 kWh/m2/yr metered electricity 16 kWh/m2/yr metered nat. gas
	Other material categories	Identical assumptions for all four buildings	Identical assumptions for all four buildings
Steel building	Concrete	Not applicable	Recycled concrete
	Steel	Recycled steel	Recycled steel
	Timber	Not applicable	Sustainable timber
	Operational energy	70 kWh/m2/yr metered electricity 16 kWh/m2/yr metered nat. gas	70 kWh/m2/yr metered electricity 16 kWh/m2/yr metered nat. gas
	Other material categories	Identical assumptions for all four buildings	Identical assumptions for all four buildings

6.4.3.2 Green Star Recycling Scenario

The Green Star Recycling Scenario takes recycling in all buildings into account. In order to provide a fair comparison, the maximum points for each material were applied. This means for example that concrete in the Timber building has been recycled, but on the other hand that the timber in the Concrete building was FSC certified. However, if less than 1 % of the total project value is due to the cost of steel or concrete materials respectively, the option ‘not applicable’ is available. The cut off rule for timber is 0.1 %.

In details the following assumptions and choices in Green Star were made:

Timber building

- Concrete recycling was taken into account. The N/A option can only be ticked if the contribution of concrete is less than 1 % of the project’s total contract value. For the Timber building, concrete is required in the foundations. Although detailed data on the cost contribution of specific materials was not available, the contribution in terms of mass was > 1%. The recycling option was therefore assumed.
- The N/A option for steel can only be ticked if it is less than 1% of the project’s total contract value. Because the cost contribution was not available, the decision was based on the material contribution which was less than 1 % and N/A was ticked.
- Operational energy figures specific to the Timber building were included (73 kWh/m^2/yr metered electricity and 15 kWh/m^2/yr metered natural gas).s
- All other assumptions were identical with the TimberPlus, Steel and Concrete building.

TimberPlus

- The same assumptions as for the Timber building were applied. The additional amount of timber in the TimberPlus building cannot be accounted for in the Green Star tool.
- Operational energy figures specific to the TimberPlus building were included (70 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered natural gas).
- All other assumptions were identical with the Timber, Steel and Concrete building.

Concrete building

- The steel contribution was less than 0.5 % and consequently the N/A option was chosen.
- The cut off criteria for timber is 0.1 % and more than this value of timber was used. FSC certified was therefore taken into account for the Steel building.
- Operational energy figure specific to the Steel building were included (68 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered natural gas).
- All other assumptions were identical with the Timber, TimberPlus and Steel building.

Steel building

- The cut off criteria for FSC certified timber is 0.1 % and more than this value of timber was used. FSC certified was therefore taken into account for the Steel building.
- The concrete contribution was > 1 % and recycled concrete was chosen for this scenario.
- Operational energy figure specific to the Steel building were included (70 kWh/m^2/yr metered electricity and 16 kWh/m^2/yr metered natural gas).
- All other assumptions were identical with the Timber, TimberPlus and Concrete building.

6.4.4 Results

The number of points awarded (only for the two categories materials and energy), as well as the weighted total score (based on those two categories) for the Steel, Concrete, Timber and TimberPlus building are shown in Table 6.14.

The weighted score is calculated in the Green Star tool based on the weightings shown in Table 6.12. Categories for which “not applicable” was chosen are excluded from the weighting, i.e. it leads to a different result if N/A is ticked or if 0 credits are awarded.

Table 6.14: Green Star results – base scenario.

	Timber	TimberPlus	Steel	Concrete
Recyclables Storage	0	0	0	0
Re-use of Façade	N/A	N/A	N/A	N/A
Re-use of Structure	N/A	N/A	N/A	N/A
Shell and Core or Intergrated Fit out	0	0	0	0
Recycled Content of Concrete	N/A	N/A	N/A	3
Recycled Content of Steel	N/A	N/A	2	N/A
PVC Minimisation	0	0	0	0
Sustainable Timber	2	2	N/A	N/A
Carpet	N/A	N/A	N/A	N/A
Paints	0	0	0	0
Thermal insulation	0	0	0	0
Non-carpet floor coverings	N/A	N/A	N/A	N/A
Credits for material	2	2	2	3
Credits for energy	3	3	3	3
Total credits	**5**	**5**	**5**	**6**
Weighted score	**5**	**5**	**5**	**6**

The environmental ranking of the buildings based on the Green Star results would be

- Concrete
- Steel/Timber/TimberPlus (all joint equal)

In comparison the LCA results for primary energy use as well as GWP in the base scenario are shown in Table 6.15.

Table 6.15: LCA results – base scenario

Ranking	Primary energy	GWP
1	TimberPlus	TimberPlus
2	Concrete	Timber
3	Timber	Concrete
4	Steel	Steel

Table 6.16: Green Star results – recycling scenario.

	Timber	TimberPlus	Steel	Concrete
Recyclables Storage	0	0	0	0
Re-use of Façade	N/A	N/A	N/A	N/A
Re-use of Structure	N/A	N/A	N/A	N/A
Shell and Core or Integrated Fit out	0	0	0	0
Recycled Content of Concrete	3	3	3	3
Recycled Content of Steel	N/A	N/A	2	N/A
PVC Minimisation	0	0	0	0
Sustainable Timber	2	2	2	2
Carpet	N/A	N/A	N/A	N/A
Paints	0	0	0	0
Thermal insulation	0	0	0	0
Non-carpet floor coverings	N/A	N/A	N/A	N/A
Credits for material	5	5	7	5
Credits for energy	3	3	3	3
Total credits	**8**	**8**	**10**	**8**
Weighted score	7	7	8	7

For the reutilisation scenario, the environmental ranking of the buildings based on the results of the Green Star rating would be:

- Steel
- Concrete/Timber/TimberPlus (all joint equal)

For comparison, Table 6.17 shows the LCA results for primary energy use as well as GWP in the reutilisation scenario.

Table 6.17: LCA results – reutilisation scenario.

Ranking	LCA reutilisation scenario - Primary energy	LCA reutilisation scenario - GWP
1	TimberPlus	TimberPlus
2	Concrete	Timber
3	Timber	Steel
4	Steel	Concrete

6.5 Discussion and Conclusions

The following Discussion and Conclusions is presented by Scion and specifically addresses only the LCA investigation undertaken by Scion and detailed in this Chapter 6.

6.5.1 Life Cycle Assessment

This study reinforces the growing recognition both in New Zealand and worldwide for a full life cycle approach to analysing and understanding the different environmental impacts of different building designs. A rigorously applied Life Cycle Assessment approach is able to identify differences in the environmental impacts of different building materials. However, it has also shown that the differences between the construction materials in the buildings do not dominate the overall results. Each building's operational phase, especially the operational energy, is the most significant contributor.

The consideration and results from investigating carbon storage in timber placed in landfill have shown that the potential release of methane has a significant influence on the overall material related results. The net storage of carbon in landfilled timber, which is one of the scenarios that is relevant in a full life cycle approach, does not influence the overall results significantly because the results are dominated by the operational phase.

6.5.2 Primary Embodied Energy and GWP

The designing of four multi-storey buildings, each utilising different construction materials but ensuring that operational energy consumption over the lifetime of the buildings was very similar, enabled meaningful analysis of the importance of embodied energy and GWP to take place.

The results show that the TimberPlus building has by far the lowest initial embodied energy and GWP contributions, followed by the Timber building. This is because the TimberPlus building contains less aluminium and steel compared to the other building types, instead substituting timber-based products, such as Western Red Cedar louvres and pine cladding.

The Steel building had the greatest embodied energy and GWP contribution (followed closely by the Concrete building for GWP), mainly caused by the large quantity of structural steel in the Steel building and pre-cast concrete in the Concrete building, where both materials have high embodied energy and GWP. However, taking the full life cycle including operational energy into account, the difference between the four buildings was relatively small.

The main impact contributors for all building in terms of building components were louvres, windows, and structural elements, all of which contained relatively large quantities of aluminium (louvres and windows) and steel (structure).

When comparing each stage in the life cycle over the full life cycle, operation of the building contributed the highest percentage to energy consumption at around 90% and GWP at around 80%. This is largely due to the reasonably long 60 year lifetime considered, as well as the relatively large building size with high energy requirements. These percentages would reduce in the future if the building is modified to become more energy efficient.

The contribution of initial embodied energy and GWP to the overall life cycle results is highest for the Steel building at 11% and 23% respectively. The end-of-life phase was dominated by the energy used to operate a landfill and the potential methane emissions from the partial decomposition of timber. The carbon stored in the wood that was sent to landfill, was subtracted from the end-of-life GWP. The TimberPlus building, being composed largely of wood, had the greatest net CO_2eq sequestration (511 tonnes CO_2eq), and the Steel building, containing the least wood, had the least at 14 tonnes CO_2eq. These reductions, in terms of the overall impact on the building's life cycle; account for reductions of up to 9% (TimberPlus) of the total GWP. The GWP benefit from carbon stored in landfills increases as more methane is able to be captured and converted to CO_2 (which has a much lower GWP value than methane). If the captured methane is used for energy (for example, as is presently happening at Burwood landfill in Christchurch, where the methane is collected and used for energy for heating the QEII swimming pool complex) there will also be a benefit for the net primary energy balance over the life cycle of the buildings.

6.5.3 Maintenance Related Energy

Maintenance of the buildings over the 60 year lifetime contributed relatively minor environmental impacts compared to the initial embodied energy and GWP. However, there were noticeable differences, in maintenance impacts, between building types and building components.

The Steel building had the greatest maintenance related impacts, whereas TimberPlus had the smallest. Fewer materials were required to maintain the TimberPlus building. Western Red Cedar, which lasts 60+ years, was used for louvres, balustrades, and reveals. Therefore, these structures do not require replacement, resulting in a greatly reduced overall impact for the TimberPlus building.

However, the TimberPlus building did have the greatest maintenance related impact for interior walls and ceilings components. This is due to the replacement of MDF panels which have a lifetime of 40 years. Even though the TimberPlus building had a higher maintenance related impact from replacing MDF interior linings and ceilings, the energy recovered from combusting these timber components, in the reutilisation scenario, reduced the overall embodied energy. Additionally, the carbon storage in the landfill scenario and the offset of emissions from fossil fuels in the reutilisation scenario result in GWP reductions for these timber components. This cannot be done for the other building types as they use materials (e.g. gypsum board) that are not combustible and, therefore, are sent to landfill.

The building components that required the most maintenance, with the largest contribution to total maintenance related impact, were the windows. This is indicative of the large quantity of aluminium required in the maintenance of the frames. The exception is TimberPlus which had the lowest impact as much of the aluminium componentry of the windows is replaced with Western Red Cedar. For the TimberPlus building, the reduced impact of the windows category outweighs the higher impacts in interior wall and ceiling categories

Some studies have shown that building maintenance can be greater than the initial embodied impacts. Therefore, the building designs in this study are very good in comparison, as associated building maintenance only contributes around 1% to the total impact and between 11% (Steel building) and 17 % (TimberPlus) of initial embodied energy.

This shows that if a building is well designed and constructed, even if embodied energy is relatively high, maintenance impacts will be much lower over time which decreases the overall life cycle impact.

6.5.4 Comparison Between Landfilling and Material Reutilisation

The results show a variation in end-of-life impact between landfilling (creating carbon storage) and material reutilisation (combusting wood for energy recovery, and recycling structural concrete and steel). These results showed that the reutilisation scenario resulted in a reduction in total energy consumption in all buildings of 0.5% (Concrete) to 4% (TimberPlus) when compared with the landfill scenario. The reutilisation scenario also showed similar benefits for GWP for the concrete and steel buildings, with 0.2% (Concrete) and 5% (Steel) reductions respectively. Conversely, in this scenario, the Timber and TimberPlus buildings showed an increase in total GWP of 0.5 and 1% respectively, when compared with the landfill scenario.

The GWP of the Steel and Concrete buildings decreased in the reutilisation scenario due to avoidance of production of primary materials (aggregate and primary steel). In the Timber and TimberPlus buildings, landfilling showed a carbon storage benefit, while combusting the wood for energy displaced the use of fossil fuels. Overall the GWP results for Timber and TimberPlus buildings in the two scenarios showed a slight favour to landfilling, though the results are so similar that no real conclusion can be made other than that both options result in a negative end of life GWP figure, which reduces the total life cycle GWP.

Material reutilisation enabled a recovery of energy for all building types. Reutilisation recovered a proportion of the embodied energy of the wood that would otherwise be wasted if the wood was landfilled. Therefore the buildings with the largest energy recoveries were the TimberPlus and Timber buildings, as these buildings were composed largely from renewable wooden materials that could be combusted for energy recovery. The Steel building also had a reduction in energy use when the structural steel was recycled, as production of primary steel is avoided.

Recycling the steel and concrete in the reutilisation scenario would be more beneficial than simply landfilling these materials because this displaces the need to use new primary materials – in the case of steel these materials have a high initial embodied energy and GWP. For the Concrete building the differences are not as pronounced, however there are still slight GWP and energy reductions as a result of material reutilisation.

In summary, reutilisation shows clear benefits for the Steel building. The Concrete building has energy and GWP benefits from reutilisation, though they are small enough to be affected by changes in transport distances. Both scenarios result in end of life GWP reductions for the Timber and TimberPlus buildings. However, the reutilisation scenario shows the additional benefit of energy recovery and displacement of fossil fuels.

The comparison between the two end-of-life scenarios shows that conclusions based on a single indicator could lead to unintended outcomes. Using the TimberPlus building as an example, the results of the landfilling scenario would be slightly better in terms of climate change. However, looking at the energy results alongside the global warming potential results, the reutilisation scenario shows an energy reutilisation benefit, as well as still being beneficial to climate change. Therefore, the use of multiple indicators is necessary to inform environmental decision-making processes.

6.5.5 Transport Distances Sensitivity Test

The analysis of different transport distances has shown that the contribution of transport to the total life cycle is not significant. Differences between the short and long distance scenarios were minimal.

6.5.6 Green Star assessment

There are clear differences in the results based on the Green Star assessment and the LCA. The results of both tools were not consistent and it became obvious that the recycling content of steel and concrete drive the material related results. The reutilisation scenario in the LCA study has shown that there are environmental benefits related to the energy use of post-consumer timber. These environmental benefits can not be recognised in the Green Star assessment tool. The LCA reutilisation scenario has also shown that the recycling benefits for steel are more significant than the benefits for recycling concrete, whereas Green Star offers a maximum of 3 points for recycled concrete and only 2 points for recycled steel and the use of sustainable timber respectively.

The different cut off rules for steel and concrete (i.e. 1 %) and timber (0.1 %) also distort the results. The amount of steel for example is less than 1 % in the Concrete, Timber and TimberPlus buildings. The questions relating to steel are therefore not applicable in those building types.

However, concrete and timber have to be accounted for in every building type respectively. The credits for recycled concrete and FSC certified timber lead then to the result that the Steel building comes out best in the recycling scenario, which awards points for recycled concrete and sustainable timber in addition to the points for recycled steel.

On the other hand, the proportion of steel is less than 1 % in the Concrete and Timber buildings, and consequently no credits are awarded for steel because the “Not applicable” option applies. Therefore, those buildings gain less points in total.

It was also not possible to take the total amount of timber into account. Whereas the LCA has shown clear differences between the Timber and the TimberPlus building, both have the same results in the Green Star assessment.

The higher weighting of energy (25 %) than materials (10 %) for the single score of the Green Star rating can be described as being consistent with the LCA study which has shown that the operational energy consumption (as compared to the embodied energy of materials) dominates the results over the whole life cycle.

7 Building Construction

This chapter is based on the work undertaken by Smith (2008) on his Master of Engineering thesis, '*Hybrid Laminated Veneer Lumber Buildings; Detailing, Feasibility and Constructibility*'.

'Constructability' – the ease and speed of construction - of any new system is crucial to the feasibility of that construction method. Speed of construction will quite obviously affect the overall cost of any building (for instance, the length of time that an expensive crane has to be on-site). However, it is also important to realise that quicker construction could offer an *opportunity cost saving* – a shorter period of construction can allow an owner / tenant to occupy a building sooner.

In order to analyse and compare the constructability of different buildings, encompassing both *materials and labour*, it is necessary to understand the proposed construction method and ensure that it is both feasible and optimised.

The beginning of this chapter briefly outlines the construction method of the proposed post-tensioned Timber buildings and the pre-cast Concrete building. A comparison is presented between the construction times of the two buildings.

7.1 Construction Method of the Timber Buildings

Well-planned construction methodology can dramatically reduce the amount of time taken in the assembly of a structure. It is crucial that the construction method utilises the off-site prefabrication of the timber members as one of the key advantages of the post-tensioned timber system. In order to assist the rapidity of construction the building was separated into three sections (Figure 7.1) enabling workers to perform tasks on separate sections without conflict. The proposed construction procedure is briefly detailed.

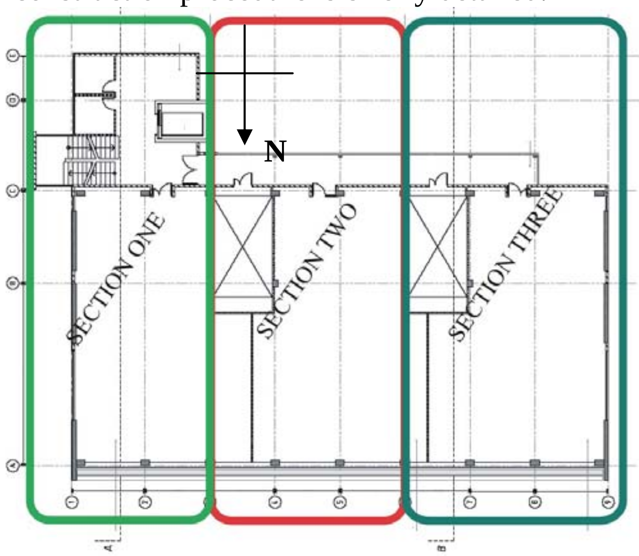

Figure 7.1: Building construction sections

7.1.1 Platform and Balloon Construction

Two main types of construction method exist for the erection of light timber buildings. These methods can also be used for the erection of a post and beam structure (Buchanan, 2007) such as the post tensioned LVL system. The first of these methods is *platform* construction, shown in Figure 7.2a in which the building is constructed on a floor by floor bases. This mean the column and wall segments will by one single storey high. This method has the advantage of providing a consistent working platform from the floor below. In the construction of light timber frame buildings, this method is not recommended for buildings above four storeys as crushing due to perpendicular-to-grain loading will become a problem. The second method is that of *balloon* construction, as shown in Figure 7.2b, where the columns and walls are continuous over several storeys and beams and flooring are then attached up the height, with the erection of three floors occurring without the additional placing of vertical members. This method can save construction time due to less members being assembled on site. The prefabrication of members, added to the lightness of timber, means that the balloon construction method is preferred for post- tensioned timber construction.

a)

b)

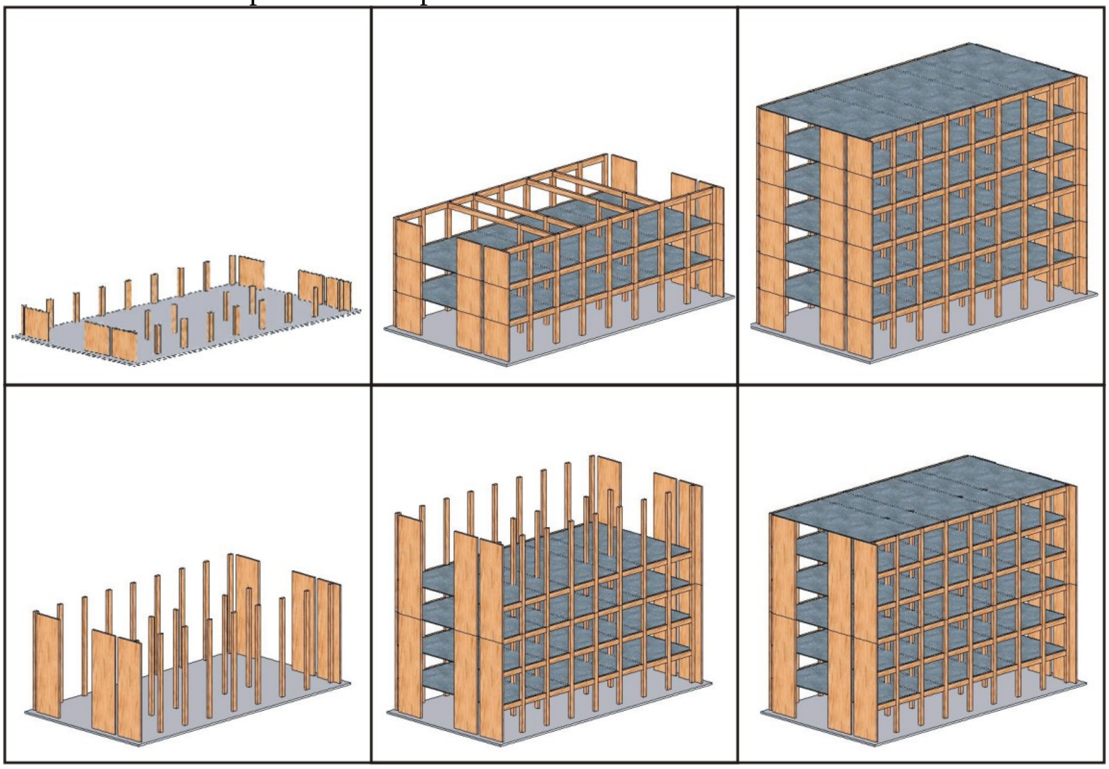

Figure 7.2: a) Platform construction method b) Balloon construction method

7.1.2 Assembly of Key Components

There are a number of key components/technologies identified with the construction of the Timber buildings which contribute to the ‘constructability’ of the designs. Current research at the Department of Civil and Natural Resource Engineering at the University of Canterbury includes;

- Wall and column to foundation attachment.
- Beam attachment.
- Timber / concrete composite flooring systems and floor attachment.
- Splicing of wall and column members.
- Post tensioning.

Further details are provided in the referenced Masters thesis.

7.2 Construction Method of Concrete Building

The construction of the alternative Concrete building would proceed in a similar manner to that of the Timber building, as both consist largely of prefabricated members. The same 'section' construction technique will be adopted. The major variation between the two buildings is that the wall and columns of the Concrete structure are only of a single storey in height, meaning that platform construction rather than balloon construction will take place. Figure 7.3 shows the assembly of this structure.

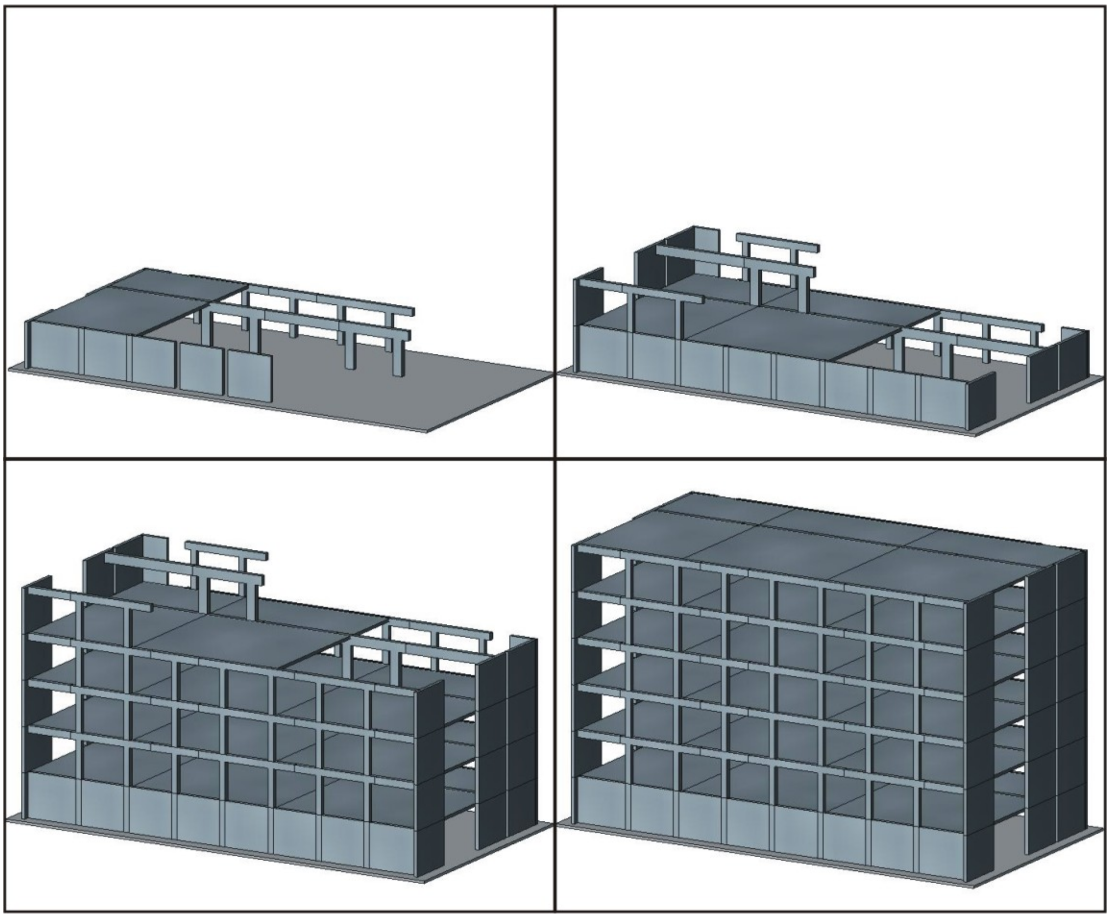

Figure 7.3: Construction of pre-cast concrete case study building

7.3 Construction Time Analysis

The time taken on a construction project can have a considerable effect on the feasibility of a given project. Therefore, one of the key performance indicators of any construction system is the overall construction time. With this in mind, the time taken to assemble the case study buildings has been analysed and compared. Arrow International Ltd., Project Management Consultants, was consulted to ensure the construction scheduling for both case studies are estimated with reasonable accuracy.

Some assumptions had to be made in order to predict the necessary time needed. These assumptions are listed below:

- Column and wall members will take one hour to erect after arrival onsite.
- Beam members will take half an hour to place after arrival onsite.
- Flooring units will take twenty minutes to place after arrival onsite.
- The floor topping will be undertaken in two pours, each taking one day.
- Architectural fit-out will not be considered for either building.
- Available personal onsite will not limit construction time.

The buildings are divided into sections in order to increase rapidity of construction. Using this information Gantt charts of the proposed construction sequence were developed for both the Concrete (Figure 7.4) and Timber buildings (Figure 7.5).

From Figure 7.4 and Figure 7.5 above it can be seen that the overall construction time for the Concrete building is 67 days and 69 days for the Timber building. The first floor of each structure take the longest time as the foundations must cure adequately. It can be seen that the sub-structure work takes almost one third of the time of construction in each building. On completion of the first level, the rapidity of pre-fabricated construction is evident. Each level of both structures takes approximately 15 days to complete.

The major point of difference between the two buildings is the method of construction used. The use of the balloon construction method means that the Timber structure only places vertical members in two lifts during construction, compared to the Concrete structure which must place wall and column members at each floor. The Concrete assembly negates this issue by using pre-fabricated members containing both column and beam elements, and as less members are required on each floor, a similar time can be achieved.

A direct comparison between the two construction times shows little difference in time meaning that comparable construction times can be achieved with the proposed post-tensioned timber construction.

ID	Task Name	Duration
1	**PROJECT DURATION CONCRETE**	**67 days**
2	**Demolition**	**10 days**
3	Site clearing	10 days
4	**Substructure**	**22 days**
5	Groundwork S1	4 days
6	Groundwork S2	4 days
7	Groundwork S3	4 days
8	**Foundation Beam GL 1**	**10 days**
13	**Foundation Beam GL A**	**10 days**
18	**Foundation Beam GL C**	**10 days**
23	**Foundation Beam GL 9**	**10 days**
28	**Gravity Column Slab GL B-3,B-4**	**10 days**
31	**Gravity Column Slab GL B-6,B-7**	**10 days**
34	**Stair well Slab**	**10 days**
37	Place reinforcing for first floor slab S1	2 days
38	Poor first floor slab	7 days
39	Place reinforcing for first floor slab S2	2 days
40	Poor first floor slab	7 days
41	Place reinforcing for first floor slab S3	2 days
42	Poor first floor slab	7 days
43	Strip Formwork	4 days
44	**First floor**	**17 days**
45	**S1**	**10 days**
46	GL 1 end walls	1 day
47	S1 GL A wall panels	1 day
48	S1 GL C wall panels	1 day
49	S1 GL B Frame	1 day
50	S1 GL C Frame	1 day
51	S1 GL B beam placed	1 day
52	Insitu column reo	1 day
53	Insitu column form	1 day
54	Insitu column pour	5 days
55	**S2**	**7 days**
56	S2 GL A wall panels	1 day
57	S2 GL B Columns	1 day
58	S2 GL C Frame 1	1 day
59	S2 GL C Frame 2	1 day
60	S2 GL B beam placed	1 day
61	Insitu column reo	1 day
62	Insitu column form	1 day
63	Insitu column pour	5 days
64	**S3**	**7 days**
65	GL 9 end walls	1 day
66	S3 GL A wall panels	1 day
67	S3 GL C wall panels	1 day
68	S3 GL C Frame	1 day
69	S3 GL B beam placed	1 day
70	Insitu column reo	1 day
71	Insitu column form	1 day
72	Insitu column pour	5 days
73	Prop and cast insitu joints	2 days
74	**Flooring**	**11 days**
75	S1 Flooring	1 day
76	S2 Flooring	1 day
77	S3 Flooring	1 day
78	Prop flooring	2 days
79	Pour topping	7 days
80	**Second floor**	**15 days**
110	**Third floor**	**15 days**
140	**Forth floor**	**15 days**
170	**Fifth floor**	**15 days**
200	**Sixth Floor**	**15 days**
230	**Roof Area**	**6 days**
231	Placement of roof portal frames	2 days
232	attachement of roof joists	2 days
233	attachement of roof cladding	2 days

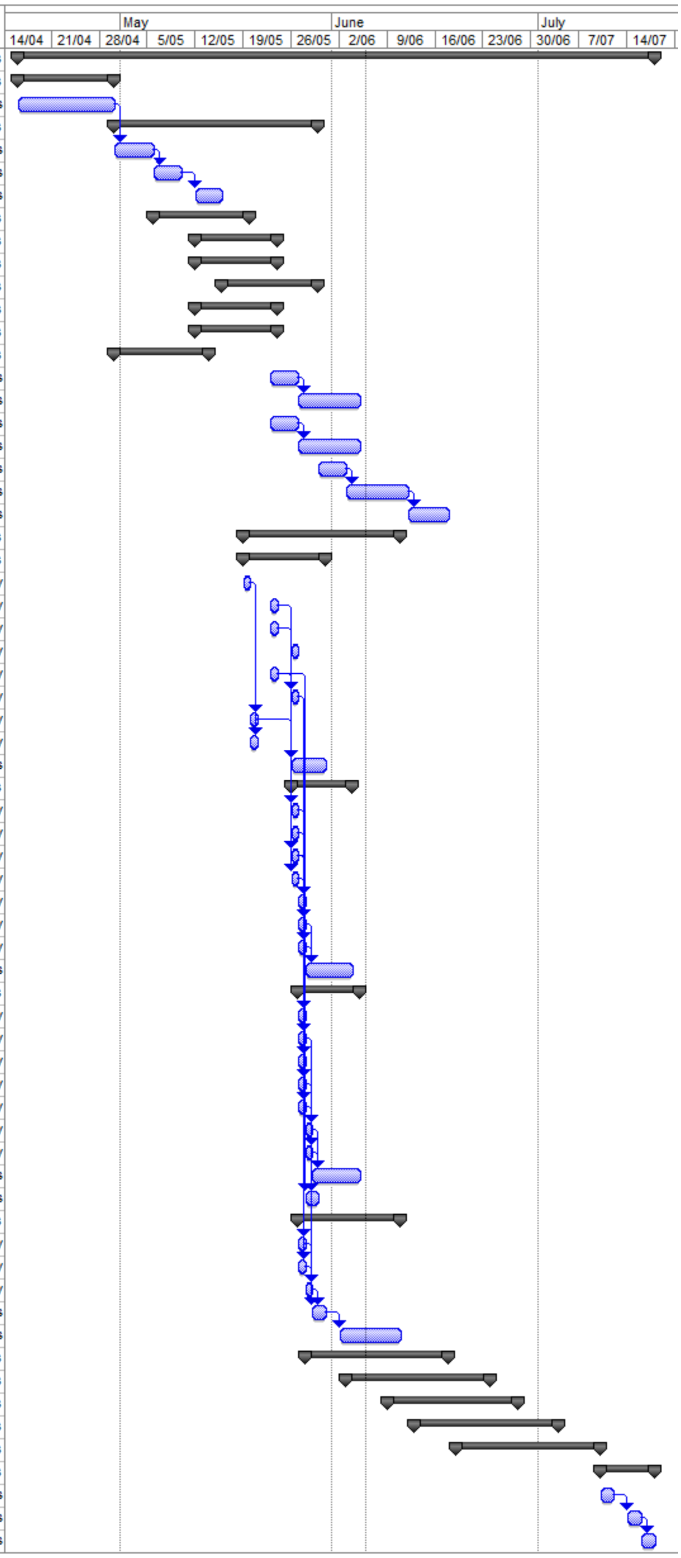

Figure 7.4: Construction schedule summary for pre-cast Concrete building

ID	Task Name	Duration
1	**PROJECT DURATION TIMBER**	**69 days**
2	**Demolition**	**10 days**
3	Site clearing	10 days
4	**Substructure**	**22 days**
5	Groundwork S1	4 days
6	Groundwork S2	4 days
7	Groundwork S3	4 days
8	**Foundation Beam GL 1**	**10 days**
13	**Foundation Beam GL A**	**10 days**
18	**Foundation Beam GL B**	**10 days**
23	**Foundation Beam GL 9**	**10 days**
28	**Gravity Column Slab GL B-3,B-4**	**10 days**
31	**Gravity Column Slab GL B-6,B-7**	**10 days**
34	**Stair well Slab**	**10 days**
37	Place reinforcing for first floor slab S1	2 days
38	Poor first floor slab	7 days
39	Place reinforcing for first floor slab S2	2 days
40	Poor first floor slab	7 days
41	Place reinforcing for first floor slab S3	2 days
42	Poor first floor slab	7 days
43	Strip Formwork	4 days
44	**First Three Storeys**	**26 days**
45	**Columns and walls**	**10 days**
46	**Siesmic Columns**	**1 day**
47	S1 Columns placed and proppec	1 day
48	S2 Columns placed and proppec	1 day
49	S3 Columns placed and proppec	1 day
50	**Siesmic walls**	**10 days**
51	GL1 Walls placed and propped	1 day
52	Pour Grout for Dissipaters GL 1	1 day
53	GL9 Walls placed and propped	1 day
54	Pour Grout for Dissipaters GL-9	1 day
55	Gravity Columns Placed	1 day
56	**First Floor**	**14 days**
57	**Siesmic Beams**	**3 days**
58	S1 Siesmic beams	1 day
59	S2 Siesmic beams	1 day
60	S3 Siesmic beams	1 day
61	Tendon Placed on GL A	1 day
62	Tendon Placed on GL C	1 day
63	Tendon Stressed GL A	1 day
64	Tendon Stressed GL C	1 day
65	**Gravity Beams**	**1 day**
66	Gravity beam 11	1 day
67	Gravity beam 12,13,14	1 day
68	**Floor Units**	**4 days**
69	Flooring for S1	1 day
70	Flooring for S2	1 day
71	Flooring for S3	1 day
72	Reo bars placed in wall	1 day
73	Floor mesh placed S1 and S2	1 day
74	Floor mesh placed S3	1 day
75	Foor propped from below S1 and S2	1 day
76	Foor propped from below S3	1 day
77	Insitu Slab Poured S1 and S2	8 days
78	Insitu Slab Poured S1 and S2	8 days
79	**Second Floor**	**16 days**
102	**Third Floor**	**13 days**
125	**Second Three Storeys**	**23 days**
126	**Columns and walls**	**6 days**
137	**Forth Floor**	**14 days**
160	**Fifth Floor**	**15 days**
183	**Sixth Floor**	**13 days**
206	**Roof Area**	**6 days**
207	Placement of roof portal frames	2 days
208	attachement of roof joists	2 days
209	attachement of roof cladding	2 days

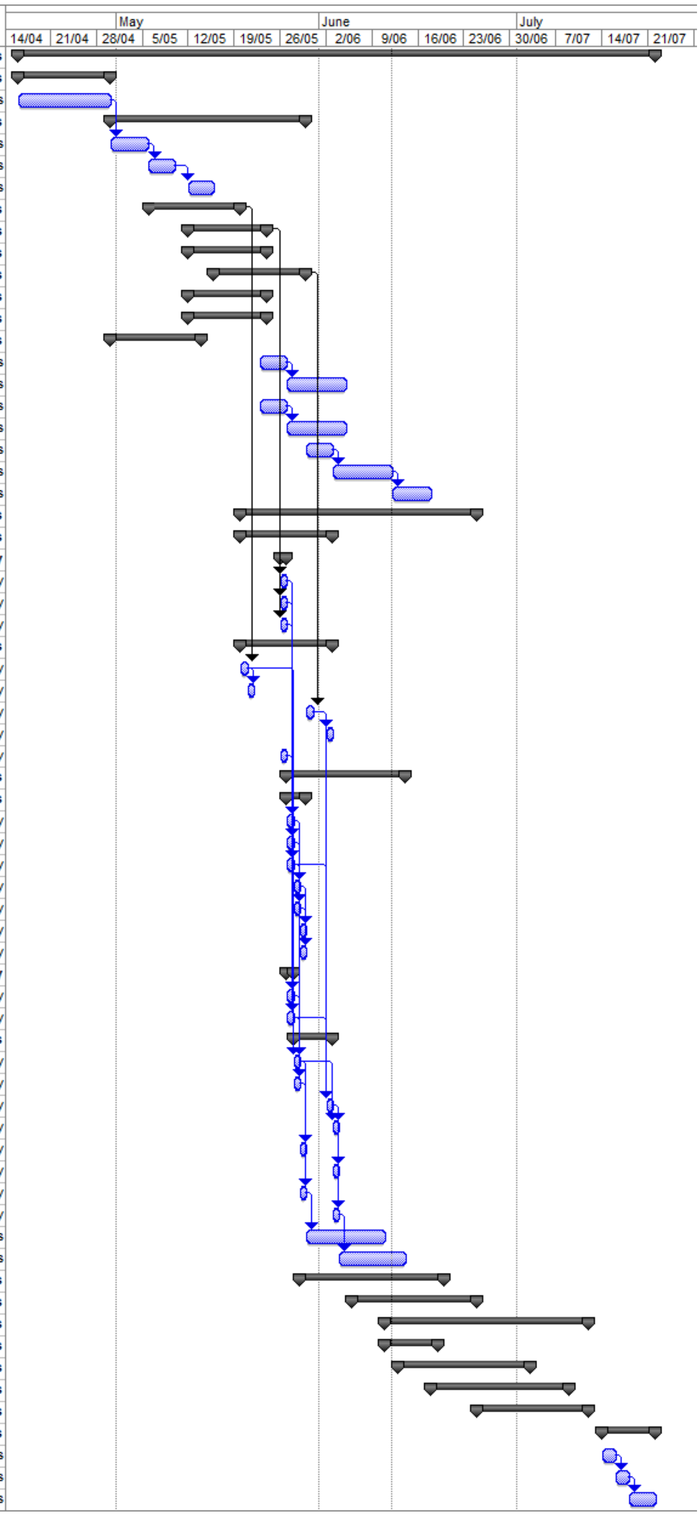

Figure 7.5: Construction schedule summary for Timber building

8 A Review of the Timber Used in the Timber Buildings

8.1 General

Warren and Mahoney architects in Christchurch were engaged to report on the supply, sustainable forestry certification and treatment of the timber materials and components of the buildings covered by this report.

A summary of the Warren and Mahoney report, included in its entirety in Appendix F, is presented below.

Whilst all four building designs use some timber materials, it is the Timber and TimberPlus designs which make extensive use of timber. Both utilise timber for the main structural components of the multi-storey buildings. However, it is the TimberPlus design which maximises the use of timber throughout both structurally and architecturally, both internally and externally (see Chapter 4, The Buildings).

The Timber and TimberPlus buildings have been rigorously designed. This research goes beyond a purely *theoretical* study of a 'timber building' to offer designs which incorporate proven engineering and are capable of being constructed today.

In order to support the proposal that the Timber and TimberPlus buildings are '*real*', it is necessary to investigate and validate the supply of the timber materials in the quantities in which they would be required and where such materials would be commercially sourced, locally or imported. All timber needs to be '*suitable*' for the location and purpose proposed.

Building rating systems, such as NZ Green Star Office design (and a raft of similar tools which are due to be 'rolled out' in NZ in the next 24 months) place emphasis on any timber materials and components being sourced from a sustainable supply. The present NZ Green Star Office design tool recognises only Forest Stewardship Council (FSC) certification. Warren and Mahoney sourced timber materials from supply chains which could demonstrate sustainable forestry certification wherever possible.

The treatment of timber, and the chemicals associated with treated timber, are issues of great importance from a 'healthy living perspective', from the impact on the environment during the production process and during lifetime usage and, of increasing importance, from the perspective of disposal of deconstructed building materials and components at the end-of-life. Section 8.6 gives a brief update on the current situation in NZ for recycling and disposal of treated timber waste.

The Warren and Mahoney report, also offers advice on additional opportunities to maximise timber in the buildings.

8.2 Source and Availability of Timber

New Zealand has a substantial forestry industry which ranges from the efficient growing of specialist plantation species through to modern harvesting techniques, to milling and treatment, the provision of engineered timber products such as laminated veneer lumbar (LVL) and Glulam and the manufacture of timber components.

Increasingly, a large range of timber products are available to offer alternative options to designers and builders for both main structural building components and architectural finishes.

NZ forestry – and hence the product supply chain – is dominated by *Pinus radiata*. This versatile timber offers a product range which, with little processing, can be used for the supply of standard framing material through to lower end value-added products such as plywood and medium density fibreboard (MDF) and increasingly through more technical manufacturing processes to engineered components, such as LVL.

P. radiata is not a naturally durable timber, often requiring treatment to extend its lifetime and useful range of applications. An alternative to treatment is to source more naturally durable species, such as Western Red Cedar. Also, for both technical and aesthetic reasons, other timber species may be more appropriate than *P. radiata* in some applications.

The Warren and Mahoney report covers each timber component of the buildings and details a commercial source which could meet the demand for the quantities specified in the building designs. Where possible, timber has been sourced from a local supply.

NZ supplied *P. radiata* was suitable for much of the structural timber, finishing and joinery including the following;

- Columns, beams, joists, shear walls and portals.
- Interior and exterior wall framing.
- Internal solid walls.
- Roof and parapet framing.
- Ceiling tiles.
- Floor.
- Internal stairs.
- Exterior wall cladding.

The TimberPlus building proposes a *P. radiata* timber exterior wall cladding, *'Shadowclad'*, an engineered product supplied by Carter Holt Harvey.

An interesting alternative for exterior cladding is the *Flatline Board System* currently under development by Australia's Timber Development Agency (TDA) (www.timber.net.au/flatline) – this is an "open-source" system which can be utilised by any cladding manufacturer. Theoretically, therefore, it could be manufactured in NZ utilising locally sourced timber.

The quantities of LVL required for the Timber and TimberPlus buildings are certainly available for supply in NZ. Plywood, MDF and framing materials are readily available "off the shelf".

NZ has a limited supply of alternative timber species, such as cedar, and, for the commercial quantities required, this has been sourced from overseas. Cedar has been proposed for all the window reveals and for the louvres.

8.3 Certification of Timber

This topic is briefly documented by the Warren and Mahoney report noting FSC and other major sustainable timber sourcing schemes. Each timber and component are covered separately and have been sourced from a 'certified' supply wherever possible.

Much of NZ's commercial *P. radiata* forestry is now covered by some form of recognised certification system, guaranteeing a level of sustainable supply (largely FSC). However, certification does not always apply to the complete supply chain and this is an area which needs further development in NZ (and internationally).

The Warren and Mahoney report notes that LVL supplied by Nelson Pine Forests for columns, beams, joists, shear walls and portals (the nearest LVL supplier for the Christchurch located buildings) is not currently certified. However, it also notes that Carter Holt Harvey Ltd. can supply FSC certified timber and LVL[11].

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[11] TimberNews (http://www.mycustompublishing.com.au/e-news/issue35.html) reported the following in the 30th June 2008 edition (the text has been edited and abbreviated to include only relevant information);

Carter Holt Harvey has engaged Ensis in Australia, the local agent for Scientific Certification Schemes (SCS), to provide certification of its mills. SCS is recognised by the Forest Stewardship Council (FSC) standard.

In NZ, SCS has so far audited ply mills at Tokoroa and Mt Maunganui and the Marsden Point LVL mill (and other CHH sawmills at Yarram, Morwell and Myrtleford and the ply mill at Myrtleford in Australia).

Carter Holt Harvey uses chain of custody (CoC) certification to ensure that all wood in its products is legally sourced from sustainably managed forests. Chain of custody certification creates the essential link between certified forests and timber processors, providing accreditation for responsible timber production across manufacture, wholesale and retail.

Forest Certification Scheme (FCS) provides chain of custody certification to timber producers and manufacturers. The scheme incorporates quality systems; material sourcing; production controls; transaction documentation, and labelling. In the case where Carter Holt Harvey (Australia) purchases products from New Zealand mills, CoC certification of key warehouses will also be required. FSC chain of custody certification lasts for five years.

Meanwhile, Carter Holt Harvey has outlined its environmental program, titled Wood Naturally, with a new video and brochure explaining the assessment program and actions the company is taking to achieve national targets for a sustainable built environment.

Environmental assessment tools are being used by CHH to ensure its practices and products are sourced and produced responsibly. The company aims to have wood products recognised for their contribution towards sustainable construction. The company has been working across a number of fronts to achieve this goal:
• Working with the CSIRO to contribute baseline data on the manufacture and processing of timber products such as plywood, particle board and MDF, which will then be used to compare the qualities of wood products with other building materials.
• Sourcing Chain of Custody (CoC) certification of all its mills in Australia and New Zealand to independently demonstrate that wood being used is sourced from sustainably managed forests.
• Communicating its environmental credentials and goals through online updates on procurement policy, mill certification and benefits of wood as a building product.

It would be incorrect, however, to assume that because something is made from *P. radiata* it can be sourced with FSC certification – each product needs to be investigated individually. Carter Holt Harvey have committed to a process of "*FSCing*" their entire product range - as shown below - so very soon, certified versions of most *P. radiata* products, when purchased directly from CHH, will be available. (CHH are leading the way in this but other manufacturers will be forced to follow suit or lose market share).

a. LVL available now FSC certified.
b. *Laserframe* and rough sawn timber / decking available now FSC certified.
c. Ply available now FSC, CoC certified (including Shadowclad).
d. MDF and Timber profiles (weatherboard etc.) FSC certification expected July/August '08.
e. *Hi-Joist* FSC certification expected Oct / Nov '08.

The *Flatline Board System* is still only a theoretical system, so theoretically *P. radiata* with an FSC rating could be used to produce this product.

Warren and Mahoney advise (Pers. comm., Iain Nicholls) that FSC certified medium density fibreboard (MDF) will soon be available from Carter Holt Harvey Woodproducts with an E1 VOC rating. (Note that in this report, MDF ceiling tiles were sourced from Nelson Pine who manufacture MDF under the brand name "*Goldenedge*". Whilst Nelson Pine is not currently FSC certified for this product, it is expected that a similar product with FSC certification could be sourced).

FSC certified cedar is available in NZ from a Canadian source.

Whilst care may need to be taken to ensure sourcing of sustainably certified timber, the supply in NZ and worldwide is increasing as certification becomes almost mandatory in international markets.

8.4 Timber Treatment and Durability

Appropriate timber treatment extends the useful range and durability of many timber products. Treatment is generally taken to mean the addition of preservatives which infuse the timber often at the time of processing of the timber (such as boron salts, light organic solvent preservatives (LOSP), etc.). However, durability is also greatly influenced by surface coatings such as paints and stains and must also be considered when investigating the environmental impacts. The Warren and Mahoney report documents timber durability classes, places all the proposed timber products within the appropriate durability class and proposes treatment methods and schedules for each timber product. The report also lists suitable timber finishes and maintenance schedules to extend durability and appearance.

Timber preservatives are listed in order of preference following the requirements of the NZ Building Code and NZS3602. Strictly adhering to these treatment methods and schedules is extremely important, applying both to timber exposed to severely harsh weathering on the outside of a building and also to more protected internal finishes.

Note that whilst the utilisation of timber waste after deconstruction (of buildings) by burning for energy production is not widely available in NZ at present (see section 8.6), it is important to consider a future scenario where timber waste could be better utilised. The type and level of treatment of timber both during its initial processing (and manufacturing if applicable) and during its lifetime could have a great effect on the suitability and, therefore, possibility of utilising deconstruction waste at the end-of-life of a building. It is certainly thought prudent to avoid CCA (copper-chrome-arsenic) treatments wherever possible.

Appropriate design of the buildings, the suitability of proposed products and awareness of durability are all extremely important to ensure the longevity of the timber-based buildings. Building design considerations ensure that structural LVL components are not exposed to damaging deterioration during the proposed lifetime of the buildings.

In keeping with current best practice, Warren and Mahoney advise that the use of CCA (copper chrome arsenic treatments) are to be avoided and, as such, wherever possible, the architects have avoided specifying CCA for any of the TimberPlus buildings components. Instead, products have been specified which have less potent ACQ treatments (or Boron treatments for lesser exposure areas, as defined by the NZBC, and *Shadowclad* is pre-treated with H3.1 LOSP azole). ACQ is a waterborne, Alkaline Copper Quaternary preservative system developed to provide long-term protection to wood exposed in exterior applications. ACQ is based on copper combined with a quaternary ammonium compound and is applied to wood by pressure treatment. Copper and quaternary ammonium compounds are effective fungicides and termiticides. Together they provide protection against a broad spectrum of decay fungi, borer and termites. ACQ can be used in all locations that CCA would previously have been specified except H6. Wherever treatments are not required by code they have avoided them.

Cedar – used externally for both window framing and louvres – requires adherence to a strict maintenance schedule. The Warren and Mahoney report notes that *"with correct maintenance of surface finishes, cedar is expected to last well in excess of the 60 year building lifespan"*.

The TDA *Flatline Board System*, proposed as the external cladding for the TimberPlus building, is a theoretical system which has been designed for *P. radiata*. There are many examples of well designed NZ buildings constructed from *P. radiata* weatherboards which have lasted well in excess of 60 years – the key is the maintenance of the coatings and the building's design avoiding the creation of enduring damp conditions. As advised by Warren and Mahoney Architects (Iain Nicholls, pers. comm.), it is expected that the TDA system would be no different.

Similarly, *Shadowclad* plywood pre-treated to H3.1 with LOSP azole, also proposed for external use in the TimberPlus building, is designated to last 50 years when properly maintained (Pers. comm. between Carter Holt Harvey and Iain Nicholls) and it was further confirmed that that there would be no reason to expect any failure during the life of a 60 year building if properly maintained.

8.5 Additional Opportunities for the Use of Timber

The Timber and TimberPlus buildings both use an increased amount of timber in their construction (over and above a comparable concrete or steel building). However, the research uncovered additional opportunities for the use of timber which were not included in the building designs analysed for environmental impacts (designs had to be finalised at a fairly early stage of the research in order for energy modelling and LCA work to proceed).

The Warren and Mahoney report identifies and provides details of some of these additional opportunities including the greater use of timber products in the ceilings and interior walls, as insulation and for floors, as well as externally.

8.6 Current Situation in NZ for Recycling and Disposal of Treated Timber Products

The conference paper "Extended Producer Responsibility of Treated Timber Waste" presented by Simon Love at the SB07 Sustainable Building conference in New Zealand in 2007 (Love, 2007) provides a good overview of the current options for the recycling and disposal of treated timber waste. A summary of the paper is included below.

Treated timber is a waste stream of significant volume in NZ. Whilst exact figures for the amount of treated timber waste are not available, an estimated production volume of 830,250 m^3 of treated timber in NZ in 2006 indicates that there is potential for a large supply of treated timber waste products in future years.

Untreated timber, with no chemical preservatives, has many recycling options such as reuse, mulch, fibreboard, chipboard, animal bedding, compost and energy/heat recovery. Indeed, the utilising wood waste for the production of energy by thermal treatment (burning) is widely used in some sectors of NZ industry (for instance, in sawmills and timber processing plants). Recycling of untreated wood waste appears to be market-driven, with the recyclers receiving wood waste for a fee, and selling mulched wood products to customers. These products are usually chipped wood for boiler fuel or shredded wood for use as garden mulch.

However, utilising treated wood waste with infused chemical preservatives and/or superficial paints and stains presents a much more problematic situation due to the presence of toxic products, such as arsenic and the possible release of harmful chemicals in to the atmosphere.

Extended producer responsibility (EPR) is seen as an essential step towards being able to utilise timber waste.

8.6.1 Thermal Treatment

Thermal treatment encompasses incineration, gasification and pyrolysis. Incineration involves burning the timber waste in air. This can result in the volatilisation of the chemicals in the wood, particularly arsenic when CCA-treated timber is burned. For an incineration process to be considered as an environmentally responsible end-of-life solution, the emissions from the incineration process must be within acceptable limits. This could be achieved with a filtration system. Incineration plants are currently being used to dispose of only untreated waste wood in Europe.

Gasification of waste wood involves the extraction of gaseous fuel from wood by heating in an oxygen-free environment. The gas from the wood (which can include hydrogen and methane) is then mixed with oxygen and used for energy production, for example in gas turbines. This method can be an effective way of recovering energy from waste wood. The problem with using gasification for waste treated timber is the same as with incineration. Gasification usually occurs at above 800 °C, and at this temperature volatilisation of arsenic will occur. Again the waste gas stream would have to be cleaned before it could be released to the atmosphere. Currently there are no commercial projects that use gasification to process treated waste wood.

Pyrolysis is a similar process to gasification, except the decomposition of the wood happens at much lower temperatures (<700 ºC, can be lower than 400 ºC), though this is also conducted in an oxygen-free environment. Pyrolysis results in three products: pyrolysis oil, pyrolysis gas and charcoal. A lower temperature process may still result in some arsenic being volatilised, however a 2005 report states that "the amount of arsenic volatilised [in a pyrolysis process] is much less compared to gasification or incineration and therefore the arsenic released may be easier captured by for example chemisorption"(Helsen, 2005).

An example of pyrolysis being used for large-scale thermal treatment of treated wood is the *Chartherm* process. This process has been developed in lab-scale and pilot plant experiments, and a fully functional industrial plant has been successfully operating for a year. The plant can process roughly 10,000 tons of treated wood per annum. The process is a low-temperature pyrolysis, which results in some energy production, and end products of metals/minerals and clean charcoal (separated in a centrifuge). The biggest upsides to this technology are that the metals in the treated timber would not reach the atmosphere, the system can process all types of treated timber, and there is no sorting of input timber waste needed (no harmful consequences if untreated timber is in the mix). The downsides to the *Chartherm* process are that the waste metals/minerals at the end of the process still need to be separated into individual components, and that the energy balance shows that some extra energy is needed to run the process – it is not completely self-sustainable (unless the calorific value of the charcoal is taken into account). The carbon product however could be sold, or used as fuel for extra energy.

8.6.2 Pre-Processing and Chemical Removal

Research has been conducted into methods of removing the treatment from timber, thus rendering it safe for recycling, landfill disposal or incineration without the use of complex filtration systems. These techniques include chemical removal, bioremediation, electro-dialysis and a small number of other treatments. These other treatments are in general elaborate, time consuming, expensive and in general unfeasible, and will not be discussed in this report.

Cooper (2006) describe using a peroxide solution to remove CCA treatment from timber, with average extraction efficiencies of 95% for chrome, 94% for copper and 98% for arsenic (Cooper, 2006) This technique involved placing the wood in a 10 % H_2O_2 solution at 50 °C for 6 hours. The advantage of this method is that further processing of the solution can result in re-use of the treatment chemicals for further timber treatment.

Bioremediation is a term used when biological agents are employed to remove timber treatment chemicals. The technique is often employed in conjunction with other methods. For example, removal of CCA treatment from treated wood has been demonstrated using oxalic acid and copper-tolerant bacteria. (Clausen, 2004) This process reported removal rates as high as 83 % for Cu, 86 % for Cr, and 95 % for As. The downside to this technology is the time and expense needed to complete this extraction. The method involves an 18-hour extraction using oxalic acid to remove the chromium and arsenic, followed by a 7 to 9 day bioleaching process to remove the copper. Some brown-rot fungi have displayed copper tolerance, and have been successfully used for the purpose of treatment extraction. (Taylor, 2005).

Electro-dialytic remediation is a method developed and patented at the Technical University of Denmark (DTU). It uses an electric current to mobilise the metal ions in solution, and an ion exchange membrane to then separate the electrolytes out. Prior to electro-dialytic treatment, wood is soaked in solutions of oxalic acid or a combination of phosphoric acid and oxalic acid. In experiments, this type of electro-dialytic treatment removed up to 87% of the Cu, 81% of the Cr and >95% of the As in wood. (Christensen, 2004).

All of the remediation techniques mentioned above have a major drawback; that is, the wood must be chipped or ground into small particles to achieve a high extraction rate. This is an energy-intensive process. Also, high volumes of wood would be difficult to process due to the lengthy time these processes take. A 10-day treatment time, plus drying time and the possibility of altered wood properties (important if the wood is to be recycled into particleboard etc.) renders these processes impractical at this current time. One very important point is that the literature articles describe how the processes result in virtually non-toxic wood, yet most of these articles neglect to mention what happens to the extraction liquid, which will have become saturated with heavy metals. The disposal or processing of this liquid could be of serious environmental concern.

An ideal solution for end-of-life treated timber would be a recycling or disposal process that can deal with treated and untreated wood, without the need for additional processing (see also section 8.6.5).

8.6.3 Recycling

A few different options for creating recycled products have been tested with treated timber. Many of these are mentioned in the 2005 UK-based report on treated wood waste (WRAP, 2005). Products such as particleboard, chipboard and oriented strand board (OSB) can theoretically be made with treated timber; however there are drawbacks to this.

Firstly, in Europe and the UK, contamination standards are set for the production of particleboard (and similar products). These standards would mean that the percentage of CCA-treated timber that could be used in particleboard production would be less than 1 %. Also, CCA-treated timber that had been subjected to oxalic acid chemical extraction and bacterial remediation displayed a reduction in integrity and strength (but an increase in elasticity) once processed into particleboard.

Standard CCA-treated wood waste used in particleboard resulted in similar physical properties, yet leaching of arsenic was relatively high. (Clausen, 2000 and 2001). Wet-processed fibreboard using CCA-treated timber can be made with very similar properties as normal untreated fibreboard, however the product is processed in water, and the cleanup of this water could pose problems due to the leaching of arsenic. In New Zealand, the Auckland

Regional Council has put in place regulations preventing the use of treated timber in particleboard production.

Wood-plastic and wood-cement composites are another potential application of recycled treated timber. Wood-cement composites can include cement-bonded particleboard, wood fibre cement boards, concrete construction blocks, acoustic barriers and roof tiles. In general, these products perform well, in some cases better than alternatives using untreated wood. Properties such as susceptibility to leaching, bending strength and stiffness can be improved.

Wood-plastic composites are at a very early stage and therefore little is known about their potential properties. Ultimately however, wood-cement and wood-plastic composites are merely shifting the problem of difficult waste further along the life cycle. Waste disposal of these composites could pose further problems at the end of these products' lives.

Mulch and compost are other potential uses for treated timber waste. However, with the surface area vastly increased, and a high exposure to water, the risk of leaching of chemicals from CCA-treated timber is likely to be multiplied many times.

8.6.4 Extended Producer Responsibility (EPR)

Extended producer responsibility (EPR) is a concept which places the responsibility for the end-of-life environmental impacts of a product on the producer. This involves facilitating return of the product to the producer, followed by processing to recycle what is possible and minimise waste. In New Zealand EPR schemes exist for cellphones, unused paint and whiteware. Internationally, schemes exist for end-of-life vehicles, electronic equipment, packaging, batteries and others. Treated wood would be an excellent target for an EPR scheme as it is a waste that is potentially hazardous, takes up unnecessary space in landfills, and has the potential for energy recovery. Also with the Waste Minimisation (Solids) Bill appearing before parliament, producers are becoming aware of the need to be responsible with their waste.

New Zealand currently has no timber EPR schemes in place for either untreated or treated timber.

However, the upcoming Waste Minimisation Bill specifies that the Waste Minimisation Authority will be set up, which will collect a Waste Disposal Levy. This levy will be charged at the time of disposal of waste, and will fund the authority, as well as funding projects to assist with waste minimisation.

The Waste Minimisation Bill contains a section on EPR (though it uses the terms EPR and product stewardship interchangeably). This Bill does not propose legislation for compulsory product stewardship/EPR schemes; it focuses on the compulsory participation of a producer only if a product stewardship/EPR scheme already exists. This participation would include provision of collection facilities, and a minimum recycling, reuse or material recovery rate of 75% of end-of-life products received at these recycling facilities. The bill also states that sufficient notice will have to be given if there is an intention to consider the need for a product stewardship programme for a product.

The Waste Minimisation Bill stemmed from the Ministry for the Environment Waste Strategy. The most relevant part of this strategy to treated timber is the statement: “By December 2008, there will have been a reduction of construction and demolition waste to landfills of 50 percent of December 2005 levels measured by weight.” This will significantly affect wood waste, as inert wastes such as concrete are already sent to clean-fills.

8.6.5 Sorting of Timber Waste

Ideally, in time, a recycling/disposal technology that can process both treated and untreated timber will eventuate. However, if this is not feasible, any recycling of treated timber waste would have to involve a sorting process to separate treated timber from untreated wood. A number of options could offer sorting solutions ranging from visual sorting and PAN stain (a stain formulation that can detect copper-containing preservatives), to X-ray fluorescence (a non-destructive characterisation technique that can detect different elements in solid or liquid samples) and laser-induced breakdown spectroscopy (LIBS; use of a laser to ablate and ionise wood into a plasma).

8.6.6 The Way Forward for NZ

The Scion conference paper “Extended Producer Responsibility of Treated Timber Waste” (Love, 2007) offers recommendations for the future utilisation of treated timber.

New Zealand’s treated timber producers should strive to establish a voluntary EPR scheme before any legislation is put in place. This would require establishing who the responsible producers of treated timber are (wood producers, treatment chemical producers, forestry companies) and what processes should be implemented to deal with treated timber waste. There are many different sorting & treatment options available, in varying stages of maturity, and the option that should be chosen depends on whether carbon sequestration, energy production or life-cycle thinking are the key priorities and also on ongoing research, such as that into leaching and decomposition rates for treated wood in landfills.

Research would give a clearer idea of whether landfilling is actually an environmentally acceptable practice for treated timber. At present, nowhere else in the world has landfilling been considered an acceptable solution for treated timber waste in the future, due to the unknowns about the behaviour of treated timber in landfills over much longer time periods

Energy recovery from treated (and untreated) timber waste provides a way to significantly reduce the volume of wood waste which would normally end up in landfills. The downside to this is that the sequestration of CO_2 in the timber is no longer a benefit, as CO_2 will be released upon incineration, gasification or pyrolysis of the timber. This is still considered a ‘carbon neutral’ process as the CO_2 that is released is essentially carbon that the plant absorbed during its life time. The debate here is between ‘carbon neutral’ processes that could provide energy, and carbon-reducing processes that take up space in landfills and could potentially leak arsenic into the earth.

Landfilling would offer carbon sequestration at the expense of leaching risks & landfill storage space, incineration would offer energy production at the expense of carbon storage, and other thermal treatments offer a clean life-cycle approach, though still at the expense of carbon storage. Without clear priorities it is difficult to recommend a ‘best’ option at this stage. Ultimately, the best option for New Zealand depends on the priorities of government and industry.

8.6.7 Current Research Into Energy Recovery from Treated Timber in NZ

The authors have been unable to establish that any research is currently underway in NZ on the utilisation of treated timber by burning. From personal communications, the authors understand that the following parties would be interested in pursuing such research.

Chemical and Processing Engineering, University of Canterbury
The authors have had personal contact with Shusheng Pang, Associate Professor in the Chemical and Process Engineering department and Director of the Wood Technology Research Centre at the University of Canterbury.

Associate Professor Pang has developed strong interests in renewable biomass energy. He is the leader of a research programme that has been awarded over $1.9 million over four years to develop a system for using wood industry wastes to produce electricity and thermal energy. As a collaborative programme, research at the University of Canterbury is being done by the University's Wood Technology Research Centre under programme leader Associate Professor Shusheng Pang and colleagues including and Associate Professor Bruce Manly of the Forestry School. The research collaborators and industry partners are the University of Otago, Page Macrae Engineering Ltd., Meridial Solutions, the Selwyn Plantation Board Ltd., and Delta S. Technologies. The research group has established links to Thermal Gasification Task of International Energy Agency (IAE) which enables exchange of research with other world leading research organisations.

However, the above programme is not currently investigating the utilisation of treated timber waste.

Future Forests Research
Future Forests Research is a new venture by the New Zealand forestry sector to enhance the value of forests and forestry for New Zealand through strategic management and implementation of research.

FFR is a partnership between the leading NZ forestry companies, NZ Forest Owners Association, the Farm Forestry Association and Scion. Membership includes Regional and District Councils and research and educational organisations.

Future Forests Limited recently applied for research funding through the Sustainable Farming Fund carbon portfolio to investigate the utilisation through thermal treatment by pyrolosis of treated timber products but was unsuccessful (Pers. Comm., Keith Richards, Theme Manager for Environmental and Social portfolio).

9 Discussion

9.1 The Buildings

Much of the research covered by this report is built solidly upon the very successful early stages of the project which produced structural and architectural designs for four buildings constructed out of different materials. These designs were all based on the exacting design specifications and drawings for the Biological Sciences building produced by Courtney Architects and presently under construction at the University of Canterbury.

In other words, the designs are based on a '*real*' building, which became a template for the alternative Concrete, Steel, Timber and TimberPlus designs. In the case of the Steel and Timber buildings, major changes were made to the structural engineering and materials, accompanied by appropriate alterations to architectural design and materials to suit a typical New Zealand location. The TimberPlus building was similar to the Timber design with additional modifications to the architecture to increase the use of timber and timber components.

All the designs are considered at least reasonably comprehensive for a preliminary design stage and address the main structural elements. All have been carefully checked and reviewed. The Steel building, initially proposed by Steel Construction NZ Ltd., was modified at the University of Canterbury in consultation with Holmes Consulting Group engineers in Christchurch (see the letter in Appendix E).

The Timber and TimberPlus buildings are based on innovative timber engineering research which builds on proven post-tensioning technology employed in pre-cast concrete construction. The timber engineering is presently undergoing rigorous collaborative experimentation and testing at the University of Canterbury, Auckland University and University of Technology, Sydney.

Most importantly, the building designs go beyond providing comparable constructions offering the same net lettable area, facilities, operations and lifetime. Each building, whilst easily meeting the standards for being a low energy building (average 86 kWh/m2/yr), achieves an operational energy consumption within 3% of each other.

The Timber and TimberPlus designs and associated research have clearly helped to "fill the information gap" identified by MAF in the Request for Proposal (POR/7811) as to the greatest amount of wood that can be used in the construction and fit-out of commercial and large-scale residential buildings in NZ.

The production of the four alternative building designs fully meets Objective 1 set out in the University of Canterbury response to RFP POR/7811.

9.2 Multi-Storey Timber Buildings

It is acknowledged that, at present, no multi-storey timber buildings with the design and structural engineering proposed for the Timber and TimberPlus buildings have been built anywhere around the world. However, all the research results to date go well beyond initial expectations and support the proposition that traditional concrete or steel multi-storey building designs could instead be constructed with timber structural elements and architecture, utilising considerably more timber materials and components.

This considerable body of research is now moving beyond the laboratory and into the commercial building industry. The Foundation for Science, Research and Technology (FRST) – a NZ Government funded research body – has approved the establishment of a new research consortium which has formed a company, the Structural Timber Innovation Company (STIC) to continue and expand research and commercialise the research output. The consortium is joined by many of the major timber producing and manufacturing companies in NZ and Australia who are providing joint funding over an initial five year period. This collaborative Consortium can itself be viewed as a major achievement in bringing together national and international companies and industry bodies (more normally used to competing with each other), producer associations and research establishments, many of which have traditionally not worked closely together, to work towards a common goal.

The success of securing substantial research funding both from the NZ Government and industry, ultimately with the aim of constructing timber buildings similar to the timber designs considered by this research, is extremely encouraging. The ideas of the research scientists are about to be put to the test in the real world of the hugely competitive, commercial building industry.

9.3 Operational Energy

A vital phase of the energy analysis and modelling objective (Objective 2), and integral to the overall research design, was the provision of alternative building designs which would all have very similar operational energy consumption.

The research demonstrates that each building easily meets the standards for being a low energy building, as well as achieving operational energy consumption for each building within 3% of each other.

The very fact that this research demanded that the buildings needed to be designed with similar operational energy usage, provided constraints on the designs. In a ‘real’ building, design would be a trade-off between many factors and engineering design, the building’s thermal envelope, the building’s services (heating, cooling and ventilation) and other internal energy demands (such as lighting) would be heavily influenced by the building’s location (geography), usage and, very importantly, by cost. This study was constrained by the designs being suited to a Christchurch location; however, the cost incurred in modifying designs (materials, etc.) to provide similar operational energy usage was not a determining factor.

In the thesis, *The influence of construction materials on life-cycle energy use and carbon dioxide emissions of medium size commercial buildings*, Perez (2008) notes that;

- The buildings tend to be '*internal load-dominated*' and their operational energy is less dependent on the thermal characteristic of the building.

- Even lower operational energy consumption could be achieved depending on the amount of insulation and thermal mass in each building.

- Thermal mass in the Timber buildings (and indeed, in the Steel building) could be provided through using more wood (as thermal mass) and also presents the future – and interesting - possibility of using Phase Change Materials.

- For any two buildings with the same total operational energy consumption, the relative amount of heating and cooling energy consumption may be very different depending on the thermal envelope and the amount of thermal mass in each building.

- For the low energy consumption buildings in this study, only 25% of the energy consumption is in heating and cooling; 75% is for lighting, room electricity, miscellaneous systems and domestic hot water.

Previous attempts to compare lifetime energy consumption and GWP of buildings have been hampered by building design – not only has the operational energy of the building been very significant but it has also differed between buildings being studied. Hence, the significance of embodied energy and other stages in the life cycle have been harder to determine and any differences in embodied energy have been over-ridden by differences in operational energy.

This research has largely eliminated the operational energy variable and has allowed the importance of other energy phases during the lifetime of the buildings – initial embodied energy, maintenance energy, transport and end-of-life –to be identified.

It should be noted that providing buildings, as above, with similar operational energy was a time consuming task, requiring numerous 'iterative' designs where materials were changed, the design 'tweaked' and then the energy modelling was re-run. This would normally be a very expensive procedure.

The operational energy design and analysis part of this research report was entirely satisfactory and met Objective 2.

9.4 The Data

Life cycle assessment is entirely dependent on the data used at various stages in the analysis. The LCA process builds on data provided at a number of points during the analysis. The quality of the data will largely determine the quality of any LCA study. The data - and associated calculations – should be clearly presented, consistent and verifiable and any calculations should be able to be reproduced.

9.4.1 Operational Energy

Perez (2008) details all the data - and assumptions - on which the energy modelling for the four alternative buildings is based. The Wellington based company e-Cubed Building

Workshop Limited provided expert energy modelling consultancy advice to this part of the project.

The simulation schedules for the buildings (occupancy, plug and lighting, and HVAC) are considered realistic and typical for a Christchurch office building.

As described in Chapter 6, a life cycle inventory dataset for New Zealand was used to calculate the primary energy content and the GWP for electricity. This dataset takes the New Zealand electricity mix as well as New Zealand specific emissions into account. Importantly, there is a high proportion of renewable energy in the electricity mix to clearly reflect the unique NZ situation (where up to 70% of electricity is generated by renewables, largely hydro-power).

As noted in the thesis, there is a tendency in simulations that the outcomes produced are lower than the audited energy consumption during occupancy. However, the average energy consumption of 86 $kWh/m^2/yr$ for the buildings is well below benchmarks (for low energy buildings) and, thus, is considered appropriate as input data for the LCA.

9.4.2 Material Quantities

Both the initial and maintenance embodied energy and GWP components of the LCA of the buildings utilises the quantities of materials used in the initial construction and the ensuing maintenance of the buildings over the 60-year life cycle.

This research employed Davis Langdon Shipston Davies (Christchurch), a well-established and experienced, local quantity surveying company, to calculate and provide the quantities of construction materials for each building design.

The Quantity Surveyor produced material listings, from the structural and architectural drawings, as shown for all buildings in Appendix A. Any building of this magnitude is constructed of many components and a very diverse range of materials. At the start of this phase of the research, a decision was taken to itemise only those materials shown – whilst this may be deemed an arbitrary listing, this was very much a *considered decision* taken in consultation with all parties including the quantity surveyor. What was most critical was to ‘capture’ and record all those quantities of materials which could have a significant contribution to either the energy or GWP impacts. Thus, a material was considered for inclusion if it was either present in large quantities or it was a material or building component which was very energy intensive (or emitted large quantities of GWP gases) in its production.

The material listing could be further refined and many more categories included. However, the additional effort would involve a much greater level of detail than was available from the structural and architectural drawings – and at much greater cost.

The material quantities are also used to determine the environmental impacts of transport and end-of-life scenarios.

The detail and accuracy of the material listings used in this research are considered to be accurate, presented at an appropriate level of detail and exceed the original project specifications.

9.4.3 Data Sets

9.4.3.1 General

The embodied energy and GWP of the various building materials is calculated by multiplying the quantities of materials in each building by an appropriate embodied energy or GWP coefficient. Thus, the coefficient data set used in these calculations quite obviously makes a significant difference to the results.

LCA is a fairly recent research technique and much of its ‘evolution’ has been based in Europe, where a number of important data sets have been developed. Due to the lack of locally produced and specific data for building materials, a number of studies in New Zealand have been based on European industry and energy data sets. Until recently, the best ‘local’ data set was produced by Alcorn (see Alcorn, A. (1995), (1998) and (2003)) but this work acknowledges that the data set is now out-of-date and has some significant deficiencies.

A recent study undertaken by Scion in collaboration with Alcorn for the NZ Ministry of Agriculture and Forestry (Nebel et al., 2009) presents a dataset for key NZ building materials; the dataset was developed using LCA studies of timber and other building materials by combining, updating and extending overseas data and NZ information. This project identified a problem in the significant variation between NZ and European manufacturing and the resulting data differences. Whilst this latest dataset is recommended for use with NZ buildings, greater accuracy will only be achieved by the rigorous collection and analysis of NZ specific data and the development of a comprehensive NZ Life Cycle Inventory database (which would include data from other sectors such as transport and energy).

9.4.3.2 The importance of a NZ-specific GWP coefficient for LVL.

The recent study “Life Cycle Assessment: Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand” (Nebel et al., 2009) has addressed some of the issues and produced a limited data set for the major building materials in NZ (see also Section 6.3.2.3.) However, a notable omission from this new data set is a global warming potential (GWP) coefficient for laminated veneer lumber (LVL). This product is proposed to be used extensively in new pre-fabricated, multi-storey timber building, such as the Timber and TimberPlus buildings in this report.

For the LCA presented in Chapter 6, Scion have used a GWP coefficient of 0.377 (Kg CO_2 equivalent per Kg of material) for LVL based on Glulam (a somewhat similar laminated timber product) derived from European industry, with some significant adaptions made to recognise;

(i) that NZ LVL is produced using a significant component of renewable energy and

(ii) that the bioenergy (solar energy) captured by timber products during the growing of the wood should not be included in the coefficient (Scion have made similar allowances for all other timber products in the new data set, as well, which is a significant departure from some of the European data sets which incorporate this bioenergy to complete an energy balance).

This figure (0.377 Kg CO_2 eq./Kg) is significantly different to the figure which would have been used in earlier studies.

However, as noted above, this new LVL coefficient is still a 'best-estimate' and has not been developed by a thorough investigation, analysis and understanding of LVL production in New Zealand.

There are a limited number of LVL producers in NZ, at least two of which have undertaken recent work to determine a NZ-specific coefficient for LVL. Nelson Pine Industries Limited has undertaken a detailed assessment through analysis of the production and extraction of the main raw material in the production process (logs) from Nelson Forests' domestic log supply chain and considering major inputs in processing operations within their own factory including assessment of the electrical energy, boiler fuel, mobile plant fuel and PF resin (note that for the wood residues used for heat generation the assessment has included the fuel and other CO_2 emissions associated with collection, processing and transport).

Nelson Pine uses a significant amount of biomass energy. When this biomass is recognised as a renewable energy source (excluded), the emissions profile of Nelson Pine LVL is 118 kg CO_2 eq./m^3. This is finished LVL product out-the-gate. (Note that stored carbon is not included in the assessment).

The density of Nelson Pine LVL at 12% moisture content is 574 kg/m3 and this gives a coefficient for Nelson Pine LVL of 0.206 kg CO_2 eq./kg.

Nelson Pine believe that planned improvements in the production process could drop this figure to under 100 kg CO_2 eq./m^3. Using the same density conversion after planned improvements could reduce the coefficient to 0.174 Kg CO_2 eq./kg.

If a coefficient of 0.206 kg CO_2 eq./kg or less was used for LVL in the LCA study in Chapter 6, there would be a reduction in embodied GWP emissions associated with the Timber and TimberPlus building, both of which use a significant amount of LVL in their structure.

The work undertaken by Nelson Pine has not been independently reviewed at this stage and compatibility with other datasets used in this study, with regard to system boundaries and other methodological issues, could not be established. Therefore, the dataset was not applied in this study

9.5 Permanent Carbon Storage in Wood Products; an Alternative Scenario.

The LCA conducted by Scion and detailed in Chapter 6 covers the full life cycle of the buildings – often referred to as a 'cradle to grave' assessment. All life cycle assessments require assumptions about the end-of-life of the building. Chapter 6 has used two end-of-life scenarios, one being landfilling with emissions of some of the decomposition gases and the second being "reutilisation" with the wood products being burned for energy recovery. These scenarios are difficult to predict because many things may be different in 60 years time (or longer) when the buildings reach the end of their useful lives.

The following assessment will present the full lifetime GWP for the four buildings using an alternative end-of-life scenario where the there is no net increase in greenhouse gas emissions after the building is demolished. Assumptions and reasons are given below to show why this is a valid alternative way to present the results of this study.

The permanent storage scenario is consistent with the carbon sequestered in the wood products being retained permanently, that is, in perpetuity, in one of the following ways:

- Landfill of all wood products with no subsequent release of greenhouse gas emissions.
- Landfill, with any decomposition to methane being collected for energy production.
- Re-use of all wood products in other new buildings.
- Replacement of all buildings with new buildings containing at least the same amount of wood.

An excellent example of this ‘permanent storage scenario’ is occurring right now in Christchurch. The old Burwood Landfill is generating methane gas which is being efficiently collected and used to displace the use of other carbon-based fossil fuels in the heating of the QEII pool complex. By 2010, the Christchurch City Council will extend the usage of methane from Burwood by building additional piping to take the gas to the new City Offices in Central Christchurch.

The underlying consideration is that as long as the timber products ‘exist’, they are storing carbon (or displace other fossil fuel usage, as long as any ‘bad’ products of decomposition (eg. methane) are used and not released back to the atmosphere). This approach does not assume any particular end-of-life scenario; it doesn’t have to because it simply says that timber products, that are real and being utilised, store carbon, and there are mechanisms for retaining this ‘beneficial’ storage over the very long term.

The Kyoto Protocol does not recognise this approach. It considers all the carbon in wood is 100% volatilised at the time of harvesting – which it clearly is not – and has led to much debate about how to account for carbon storage in timber products.

This assessment only uses data already given in Chapter 6 of this report, presented in a slightly different way. The discussion will be in three parts; firstly, considering the materials only using those GWP coefficients adopted by Scion in the LCA in Chapter 6, then considering the materials only but calculated using figures directly from the LCA in Chapter 6, and, lastly, materials combined with all other emissions for the full life cycle over 60 years.

9.5.1 Materials Only – With Data From GWP Coefficients used by Scion.

The following data is for materials only, not including emissions from operating or maintaining the building over its life. A simplified assessment, which only considers emissions from the building materials, is essentially the same as a partial life cycle assessment which considers the building until the end of the construction phase (sometime referred to as ‘cradle-to-gate’). This scenario more clearly shows the potential benefits of retaining the carbon sequestered in the wood products.

Table 9.1 (middle column) shows GWP coefficients (Kg CO_2 equivalent per Kg material) for all the materials in the different buildings used by Scion to input to the LCA modelling process. The right-hand column of this table shows the GWP for materials where carbon storage in the timber is taken into account (see explanation below), which has a marked effect on the coefficients used for all timber products. The timber datasets are based on New Zealand log production.

The report "Life Cycle Assessment: Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand" (Nebel, 2009) notes the following:

All timber datasets are based on log production specific for New Zealand. The dataset for sawn timber is fully based on data that has been collected in a number of projects at Scion. Existing models from the GaBi database have been modified for particle board and plywood as follows. The electricity mix has been replaced with the NZ grid mix and thermal energy from natural gas has been replaced with the respective Australian dataset. It should be noted that most of the thermal energy in all datasets is generated from residual wood which is reflected in the renewable energy consumption.

Primary energy and carbon stored in the timber have not been included in the datasets presented, but need to taken into account when using the data, depending on the end of life scenario. The carbon stored in the timber will be partially released in the case of landfilling and would be fully released in the case of thermal utilisation. In an LCA study the end of life scenario needs to be defined and emissions of CO_2 *and/or* CH_4 *as well as the potential long term storage need to be taken into account. The stored carbon in wood products can be calculated as follows:*

Assumed 50% of wood mass is carbon.

=> 1kg wood = 0.5 kg Carbon
Molar mass carbon = 12 g/mol.
Molar mass oxygen = 16 g/mol
=> Molar Mass CO_2 *= 44 g/mol*

0.5 kg / 12 g/mol = 41.67 moles of carbon in 1 kg wood.
41.67 moles x 44 g/mol = 1833.34 grams.
=> 1 kg wood --> 1.83 kg of CO_2

1.83 kg CO_2 *equivalents are sequestered per 1 kg of timber.*

Table 9.2 shows the GWP (in units of CO_2 equivalent) for the materials used in the four buildings, obtained by multiplying the mass of different materials in Table 6.1 by the coefficients for each material given in Table 9.1 (right hand column). Table 9.3 shows the same data in the major groups of materials.

Figure 9.1 shows the aggregated data from Table 9.3. It can be clearly seen that emissions from concrete production dominate the emissions from the Concrete building, emissions from steel production dominate the emissions from the Steel building and emissions from aluminium play a significant part in the overall emissions of the Concrete, Steel and Timber buildings,. Whilst emissions from concrete are greatest for the Concrete building, they are notable in the other three buildings too.

The carbon sink from wood and wood products is clearly apparent in the Timber and TimberPlus buildings (but is almost insignificant for the Concrete and Steel buildings which have few wood products). There are no net emissions from the timber materials in any of the buildings. In the Timber and TimberPlus buildings, the carbon stored in the timber materials greatly exceeds the emissions associated with the production and manufacture of these timber

Table 9.1. GWP coefficients (Kg CO_2 equiv. per Kg material) for all materials in the four buildings.

Material (kg)	GWP (Global Warming Potential) [kg CO_2 Equiv.]	GWP (Including carbon storage in material) [kg CO_2 Equiv.]
Concrete, 17.5 MPa	0.102	0.102
Concrete, 40 MPa	0.158	0.158
Pre-Cast Concrete	0.17	0.17
Concrete tiles	0.263	0.263
Reinforcing steel	0.449	0.449
Structural Steel	1.802	1.802
Steel Sheet	2.284	2.284
Paint, water based	2.077	2.077
Fired clay brick	0.246	0.246
Glass fibre insulation	1.66	1.66
PE membrane (building wrap)	2.368	2.368
Fibre Cement Sheet	0.697	0.697
Aluminium, extruded.	11.312	11.312
Glass	1.36	1.36
GIB ® plasterboard	0.34	0.34
Sawn timber, kiln dried (10%)	0.154	-1.68
Particle Board	0.279	-1.55
Western Red Cedar (imported)	0.83[12]	-1.00
Laminated Veneer Lumber	0.377	-1.45
Plywood	0.21	-1.62

Table 9.2. GWP (tonnes CO_2 equiv.) for all materials in each of the four buildings.

	Concrete	Steel	Timber	TimberPlus
Concrete 17.5 MPA	6.2	6.3	5.4	5.4
Concrete 40.0 MPA	107.3	342.9	207.9	207.9
Concrete pre-cast	781.2	17.2	0.0	0.0
Steel (NZ)	10.5	139.5	7.3	7.3
Steel (Au)	31.8	478.7	10.0	10.0
Steel sheet	38.1	35.8	0.0	0.0
Stainless steel	0.0	0.0	0.0	0.0
Reinforcing steel	51.4	10.8	8.7	8.7
Glass	65.8	65.8	65.8	44.7
Timber	-18.5	-17.5	-98.0	-209.3
Western Red Cedar	0.0	0.0	0.0	-22.8
LVL	0.0	0.0	-498.7	-498.7
Plywood	-6.6	-6.6	-88.2	-105.0
MDF	-3.1	-3.1	-3.1	-109.5
Aluminium	75.0	75.0	75.0	12.0
Aluminium sheet mix	308.4	308.4	308.4	0.0
Plasterboard	13.2	19.1	14.7	0.0
Paint	1.4	1.6	2.1	2.3
Fibreglass insulation	5.6	14.1	13.4	14.2
Polystyrene insulation	6.0	0.0	0.0	0.0
Fibre cement	25.4	31.3	51.5	0.0
Net total	**1,499**	**1,519**	**82**	**-633**

[12] An updated coefficient for Western Red Cedar in NZ is 0.434 Kg CO_2 equiv. which would reduce emissions due to this material by around 10 tonnes CO_2 equiv.

products. For example, in the TimberPlus building, there is storage of 1,162 tonnes of CO_2 (Table 6.2), whilst the total production of all of the timber in the building gives rise to emissions of only 202 tonnes of CO_2 (material in tonnes, Table 6.1 x GWP coefficient in column 2, Table 9.2).

Table 9.3 Aggregated GWP (tonnes CO_2 equiv.) for groups of materials in the four buildings

	Concrete	Steel	Timber	TimberPlus
Concrete	895	366	213	213
Steel	132	665	26	26
Aluminium	383	383	383	12
Other	117	132	148	61
Wood	-28	-27	-688	-945
Net total	**1,499**	**1,519**	**82**	**-633**

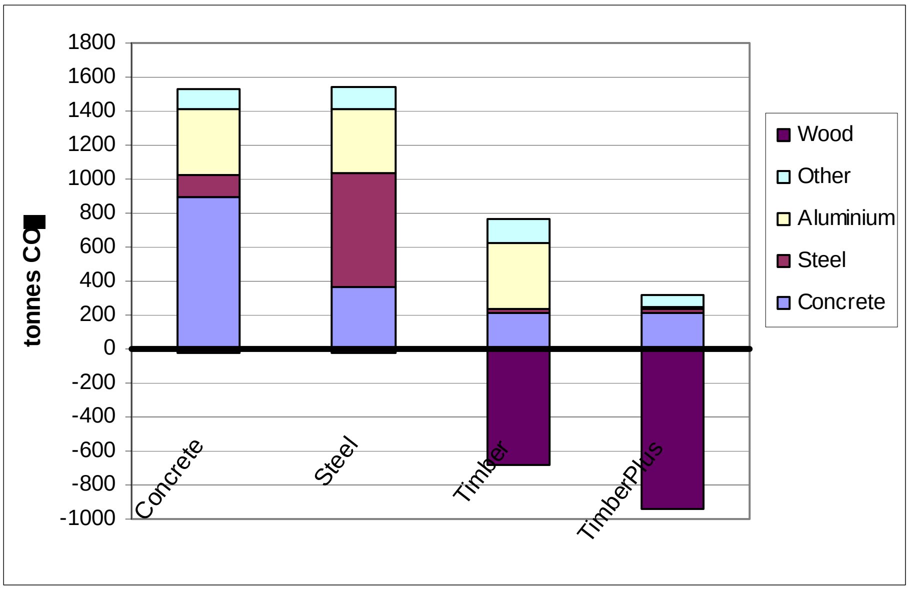

Figure 9.1: GWP emissions for the materials in the four buildings, assuming permanent storage of carbon in wood products. Data from GWP coefficients used in Table 9.3 .

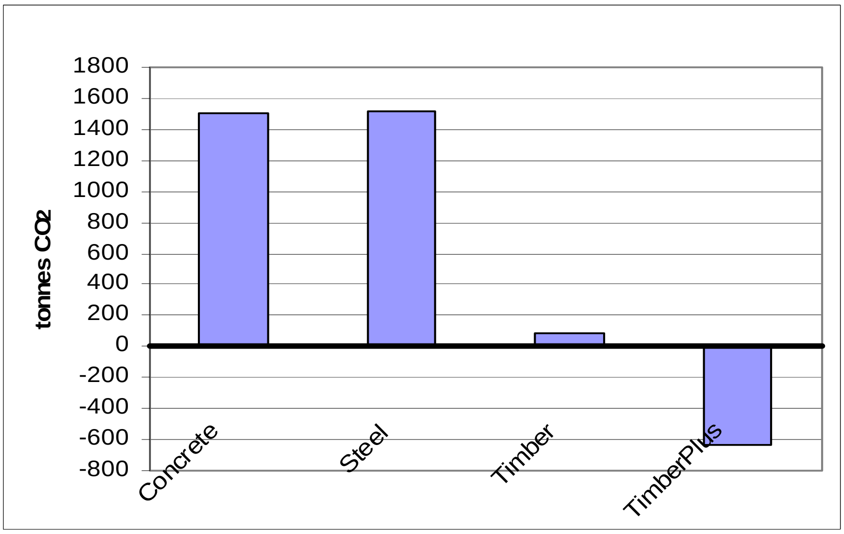

Figure 9.2. Net GWP emissions for the materials in the four buildings, assuming permanent storage of carbon in wood products. Data from GWP coefficients in Table 9.3 .

Figure 9.2 shows that the net GWP emissions from the materials in the Timber building are just 5% of those from the Concrete and Steel buildings. This is because the carbon stored in the wood-based building materials balances out nearly all of the greenhouse gases emitted in the manufacturing of all the other materials in the building.

For the TimberPlus building, the net total CO_2 emissions for the materials in the TimberPlus building are negative because the carbon stored in the wood-based building materials more than cancels out all the greenhouse gases emitted in the manufacture of all the other materials in the building. The net negative figure - or long-term carbon storage - is over 630 tonnes of CO_2 equivalent.

9.5.2 Materials only – using data from LCA assessment in Chapter 6

Another method of analysing the data in Chapter 6 is to take the results of the LCA assessment presented in Chapter 6. The top line in Table 9.4 is the initial embodied GWP (tonnes CO_2 equiv.) for all materials in each of the four buildings from Table 6.7. The second line in Table 9.4 is the equivalent CO_2 sequestered in the wood materials, derived from the wood quantities in Table 6.2. The quantity of carbon in that table has been converted to CO_2 equivalent by multiplying by 3.67 (the conversion factor for changing tonnes of carbon to tonnes of CO_2 equivalent).

Table 9.4: GWP (tonnes CO_2 equiv.) for all materials in each of the four buildings

	Concrete	**Steel**	**Timber**	**TimberPlus**
Embodied (CO_2 eq.)	1,576	1,615	971	566
Sequestered (CO_2 eq.)	-32	-31	-846	-1,162
Total	1,544	1,584	125	-596

The figures in Table 9.4 are plotted in Figure 9.3 (as separate figures) and Figure 9.4 (net figures). These graphs show similar trends to Figure 9.1 and Figure 9.2. The actual numbers are a little different from the coefficients method - the reason for this is not known precisely. The difference may be due to the unknown assumptions used to obtain the coefficients presented in Table 9.1.

However, the over-riding conclusion from using both methods, is that the carbon stored in the wood-based building materials of the TimberPlus building more than cancels out all of the greenhouse gases emitted in the manufacture of all the other materials in the building.

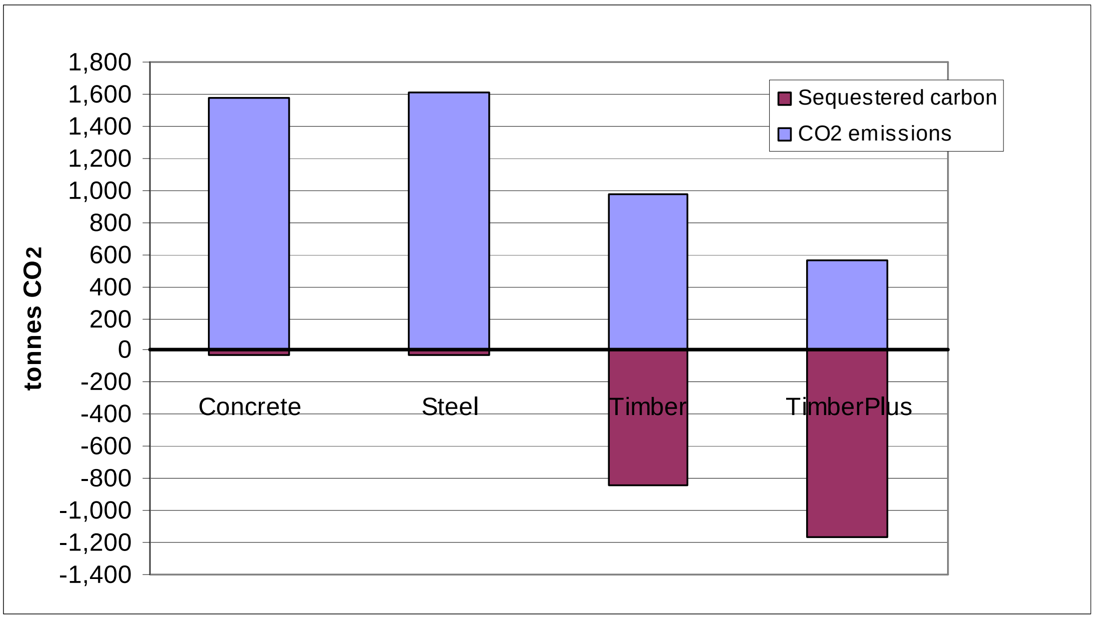

Figure 9.3. GWP emissions for the materials in the four buildings, assuming permanent storage of carbon in wood products. Data from LCA analysis in Chapter 6.

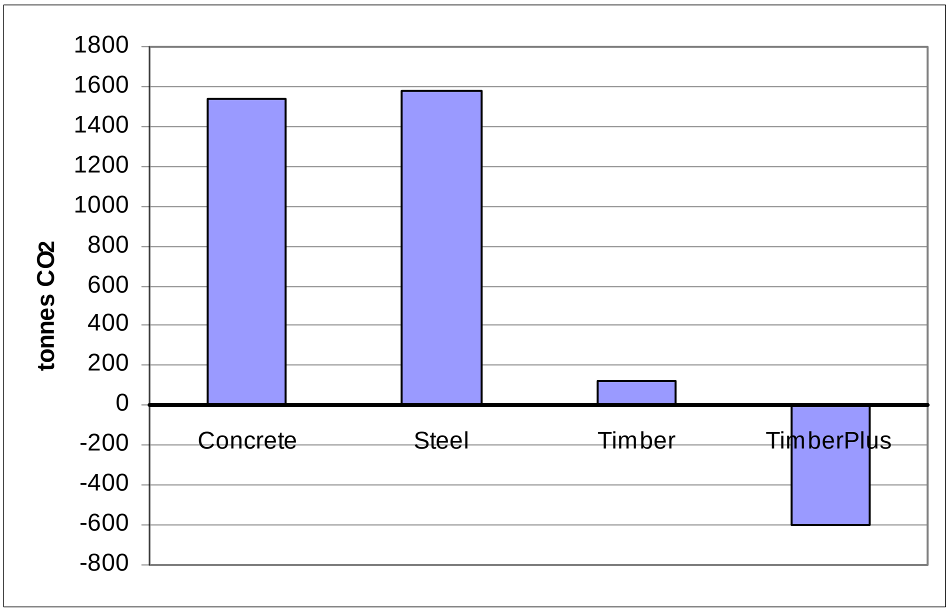

Figure 9.4. Net GWP emissions for the materials in the four buildings, assuming permanent storage of carbon in wood products. Data from LCA analysis in Chapter 6.

9.5.3 Materials Combined With all Other Emissions for Full Life Cycle

The materials data shown above can be combined with all other emissions to give a more complete lifecycle assessment. Table 9.5 shows the same data as Table 9.4, with the addition of emissions from maintenance, transport, and lifetime operational energy use over 60 years. Note that there is no GWP at all shown for end-of-life (assuming 100% storage of carbon). Whilst there should be an allowance for the 'GWP cost' directly associated with transporting, placing and retaining materials in a landfill scenario, this is not known but is considered relatively small. All data is from Table 6.7 in Chapter 6.

Table 9.5: GWP (tonnes CO_2 equiv.) for full life cycle of the four buildings.

	Concrete	Steel	Timber	TimberPlus
Embodied	1,576	1,615	971	566
Maintenance	131	166	139	99
Transport	42	39	29	30
Operational	4,910	5,000	5,161	5,038
Sequestered	-32	-31	-846	-1,162
Total	**6,627**	**6,789**	**5,454**	**4,571**

The numbers in Table 9.5 are plotted in Figure 9.5. Whilst it can be seen that operational energy use is still by far the largest source of GWP gases, it is important to note that the embodied emissions will become an even larger percentage of the total life-cycle emissions if, as following recent developments and trends, the building is re-designed in the future for lower operational energy use.

Figure 9.6 shows the net figures for each building, as given in the bottom line of Table 9.5. Whilst the differences are less pronounced than in Figure 9.4, the Timber building produces around only 80% of the total lifetime emissions of the Steel building and the TimberPlus building emits over its lifetime only around 65% of the Steel building – this is considered a significant reduction in CO_2 emissions.

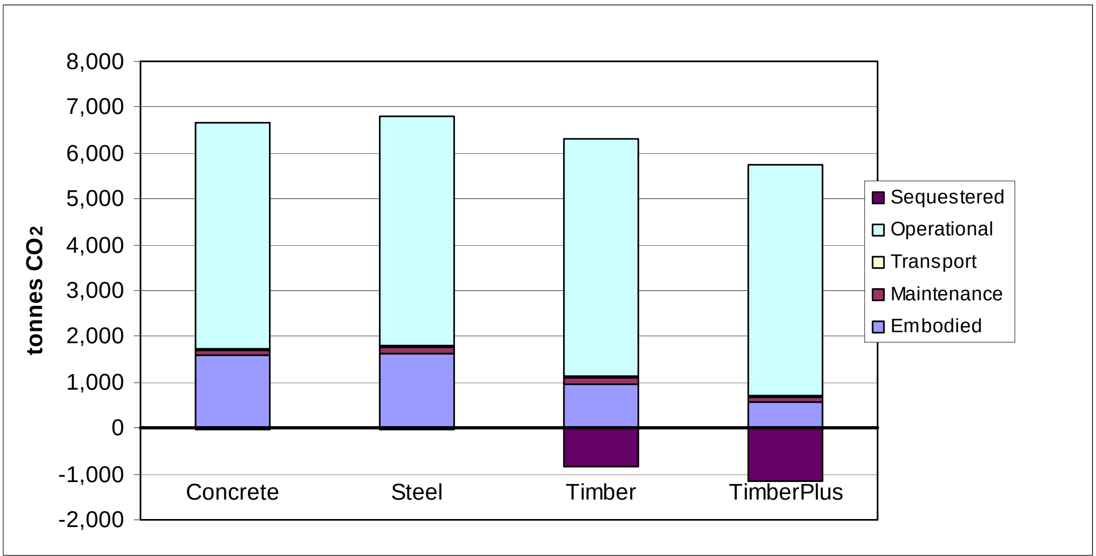

Figure 9.5. Total lifecycle GWP emissions for the four buildings, assuming permanent storage of carbon in wood products. Data from LCA in Chapter 6.

Whilst the TimberPlus building does become a net emitter of CO_2 over time, the building would be able to operate fully as a 'carbon neutral' building for around the first 12 years of its life.

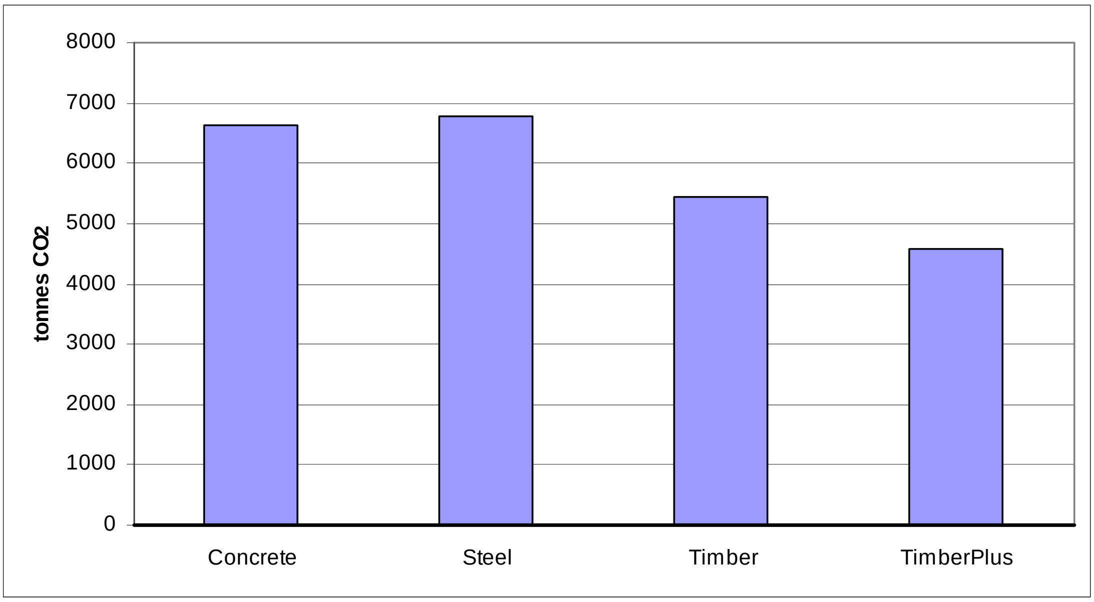

Figure 9.6. Net lifecycle GWP emissions for the four buildings, assuming permanent storage of carbon in wood products.

All of the above scenarios do not consider the carbon storage potential of products used for building maintenance and refurbishment. This could be added and would further reduce the impacts of the Timber and TimberPlus buildings. However, it would make only relatively small differences as the quantities of materials are small.

9.6 Green Star office building rating tool

The Green Star rating tool Office Design v1.0 was used to assess the four building designs, a comparison was made with LCA and a discussion of the rating tools was carried out by Scion – this is all detailed in Section 6.4

The NZ Green Building Council recently requested submissions to be made on the proposed revision of Green Star Office Design version 1.0. The timing of possible changes to version 1.0 of the rating tool is extremely topical and very relevant to this report, particularly in the area of the importance of the building materials used in everyday construction in NZ, their environmental impacts and how materials are 'treated' by the Green Star rating tool. The Department of Civil and Natural Resources Engineering at the University of Canterbury put forward a submission (30th April 2008) which is summarised below.

Supporting information for Submission to Green Star NZ, 30th April 2008 from Department of Civil and Natural Resource Engineering, University of Canterbury.

The information below is provided to support the following two submissions;

1. *We propose that Green Star New Zealand - Office Design Version 2.0 should include a CO_2 calculator and award points for overall low or negative CO_2 emissions of all the building materials used in construction (**embodied CO_2**; "cradle-to-gate").*

2. *We propose that Green Star New Zealand - Office Design Version 2.0 should include a CO_2 calculator and award points for overall low or negative CO2 emissions of the building materials used in (the predicted) maintenance and refurbishment of the building (recurrent embodied CO_2).*

Net CO_2 emissions – that is emissions (positive) or sequestration (negative) – are the primary focus of both national and international initiatives to address climate change.

This submission is supported by the recently produced document "Building for the 21st Century – Review of the Building Code" (July 2007; published by Dept. of Building and Housing). This document states '*We are considering the possibility of assessing the resources used by buildings through the carbon dioxide (CO_2) emissions associated with their construction, operation, maintenance and demolition'*.

This document further states "*We are considering CO_2 emissions …….because CO_2 is the most significant greenhouse gas associated with buildings. There are also established criteria for assessing the CO_2 associated with various forms of energy used in buildings".*

This proposal is based around adopting some of the practices of proven Life Cycle Assessment (LCA) methodologies and international standards. It provides a quantitative measure (for instance, tonnes of CO_2 per square metre of NLA) of the carbon dioxide emissions associated with the production and maintenance/refurbishment of all the materials in a building.

CO_2 emissions are derived from calculations of the embodied energy of all the building materials (both initial construction materials and those used for maintenance and refurbishment), cross-referenced with appropriate Life Cycle Inventory (LCI) data sets. Ideally these data sets would be NZ-specific (or at least 'tailored' to NZ conditions) and would need to be available and standardised across all sectors of the manufacturing and building industry. (Whilst this is not currently the case, a good start can be made using LCI data for most commonly used building materials within NZ, such as is available from Victoria University of Wellington (VUW)).

This approach recognises both the potential and the robustness of LCA implemented over the lifetime of a building but balances this against practicality and cost (LCA is a costly and complex task and there are currently few practitioners in New Zealand) to offer a solution that could be implemented and incorporated in Office Design, Version 2.

For a building, the simplified approach which we propose would measure and calculate the following:

- Initial embodied energy of significant building materials.
- Recurrent embodied energy of significant materials used in maintenance and refurbishment of the building over its proposed lifetime.
- The net embodied *CO_2* of building materials over the initial life cycle of those materials from 'cradle to gate' – that is, considering and accounting for all the *CO_2* emissions associated with the production of the building material up to the point of the material being available at the 'gate' of the production facility.
- The recurrent embodied *CO_2* of those building materials used for maintenance and refurbishment beyond initial construction – that is, considering and accounting for the *CO_2* emissions associated with the production of materials used in maintenance and refurbishment of the building.

Net embodied CO_2 includes carbon sequestered in building materials. This requires an assumption that at the end of the building's life, materials, such as wood, will either be re-used, be buried in a landfill or be burned for energy recovery in lieu of fossil fuel.

This is a simple model. It does not include;

1. CO_2 emissions from transport to the building site.
2. CO_2 emissions in construction or demolition.
3. Possible reduction in CO_2 emissions by using wood waste as an energy source.
4. Operational energy over the life-time of the building which is included elsewhere in Green Star Office Design.

Further information supporting the above methodology can be found in "Embodied Energy and CO_2 Coefficients for NZ Building Materials" (A. Alcorn, March 2003 – Published by Centre for Building Performance Research).

Embodied energy.
Embodied energy would be calculated from a building-specific listing of the major building materials, converted into gross quantities (for instance, as documented in a Quantity Surveyor's report) and cross referenced with an appropriate, simplified LCI with data applicable to NZ.

Note that only the major building materials would be considered – this could be defined as those materials which contribute to more than a specified percentage of the building by mass or volume. It would most likely, in most instances, consider at least concrete, steel, timber, glass, aluminium, paint, particleboard/fibreboard, gypsum board, masonry and insulation.

This recognises the environmental impact of producing / manufacturing building materials. Results would highlight materials which have a significant embodied energy "cost".

Initial embodied CO_2 would be calculated by cross-referencing appropriate LCI data for the significant materials listed above (for instance, VUW data sets).

Recurrent embodied energy.
This recognises the environmental impact of maintenance, refurbishment and replacement of building materials. Results would highlight materials which have a significant embodied energy "cost" over the life-time of a building beyond the initial construction, due to the need for frequent maintenance or replacement (but possibly demonstrating less initial environmental impact).

Recurrent embodied CO_2 would be calculated by cross-referencing data on maintenance and replacement cycles for the most commonly used materials.

Net embodied CO_2.
Overall net embodied CO_2 would be calculated from initial embodied CO_2, plus any chemical release of CO_2 during the manufacturing process, less CO_2 sequestered and then combined with recurrent embodied CO_2. Initial and recurrent embodied CO_2 could be detailed separately.

Net CO_2 – that is an emission to the atmosphere or a sequestration with removal of CO_2 from the atmosphere – is the primary focus of both national and international initiatives to address climate change. Measurement of net embodied CO_2 recognises those materials and processes that remove CO_2 from the atmosphere on a permanent (sustainable) basis.

Utilising Victoria University LCI data for building materials offers a "CO_2 footprint" for most common NZ building materials and captures the effect of CO_2 emissions during the manufacturing process (for instance in cement production), as well as sequestration (for instance in timber products).

9.7 Timber used in the Buildings.

Structural LVL dominates the quantity of timber used in the buildings. Other timber and timber components are used throughout all the buildings but much more so in the Timber and TimberPlus designs.

9.7.1 Laminated Veneer Lumber

The Engineered Wood Products Association of Australasia provides excellent information on many of the engineered wood products currently available commercially in New Zealand (and Australia) (http://www.paa.asn.au).

LVL is a hugely versatile timber product of known and consistent physical and mechanical properties, able to be manufactured to chosen specifications, including large dimensions.

The LVL specified for the structural components of the Timber and TimberPlus buildings is available as a product, in appropriate dimensions and quantities, from a number of companies in NZ. There is, undoubtedly, a large resource of plantation grown *P. radiata* in NZ to provide the raw product for the manufacture of LVL.

However, it is acknowledged that the fabrication facilities, machinery and techniques for producing key structural components – in large quantities and in large piece sizes - is not yet commercially available in NZ. These structural components must be cut and glued to precise tolerances from LVL plants, with connection devices accurately positioned.

9.7.2 Other Timber Products

The Warren and Mahoney report included in Appendix G is a very useful *starting point* for exploring the *suitability* of the specified timber used in the buildings, particularly the Timber and TimberPlus buildings. *Suitability* is the key word - this report acted as an important *reality check* on the building designs to ensure that the timber specified in the proposed designs was appropriate architectural usage (including usage in any external situation and appropriate NZ architecture), could be sourced, in sufficient quantities and from where, and from a sustainable market. The report also offers appropriate schedules and products for on-going maintenance over the life-time of the building.

The report confirms that the various proposed uses of timber in the buildings are appropriate, the different timber species are available and can be sourced both locally and internationally as necessary, and largely from a sustainable, certified forestry markets. Furthermore, the timber products are durable, with lifetimes extending to cover the full 60-year life cycle of the buildings.

The increasing recognition of various certification systems for sustainable forestry and products means that an increasing amount of suitably certified timber is becoming available both in NZ and internationally. Indeed, it is likely that consumer demand will ensure that all timber products will be sourced from sustainable forest markets in the not-too-distant future.

9.8 The Big Picture

The popular media, scientific journals, government initiatives, and international forums, to name a few, are awash with information and debate about climate change and global warming. Hand-in-hand with this, has been an explosion of interest, worldwide, in *all-things-sustainable*. 'Sustainability' is the 'buzz word' of the times.

New Zealand has signed a binding international treaty, the Kyoto Protocol, which commits the country to reducing its emissions of those gases perceived to be responsible for global warming. Irrespective of the all the debate about whether climate change is anthropogenic, just a natural, cyclical climatic variation and the time frame, it can be argued, that NZ as a country now recognises that the present *way-of-doing-things* is unsustainable.

A major focus for change rests on the need to reduce the wasteful use of energy, especially fossil fuels, and the (predominantly) CO_2 emissions associated with energy usage. Buildings contribute significantly to energy usage both in NZ and worldwide and the materials that are used to construct and maintain those buildings are themselves a significant proportion of that energy usage. Determining exactly how important building materials are in terms of environmental impacts and identifying ‘hot spots’ associated with those materials will aid understanding, focus resources and contribute to decision and policy making. Reducing the amount of energy used by buildings – both in their materials and operations – provides an opportunity to reduce GWP and contribute to NZ’s Kyoto commitments.

However, the authors firmly believe that the focus should not just be on *Kyoto and carbon neutrality*. NZ has a large plantation forest resource – which can provide a raw material for construction of buildings from single-storey houses through to multi-storey commercial buildings. Conversely and significantly, NZ does not have the raw materials to produce steel or aluminium. The NZ forest estate is a sustainable resource – largely certified as such by recognised international bodies. The timber produced from these forests is an entirely renewable material – when a tree is cut-down, a new seedling can be planted and more timber can be grown on the same piece of ground, continually ‘harvesting’ the solar energy of the sun. This process does not deplete any of the world’s resources which are becoming limited in supply. The forest and timber industry in NZ provides products which have a low embodied energy and low GWP.

Controversy surrounds the concept of carbon sequestration in both forests and timber products. Timber - and forests - clearly store carbon. Thus, the growing of timber removes carbon from the atmosphere. How long timber stores carbon and what happens at the end-of-life are the key questions as to whether forestry and timber products can be considered to provide a net removal of carbon from the atmosphere *in the long term*.

Using more timber to build in NZ and exporting more high-value engineered timber products could lead to an increase in NZ’s plantation forestry resource, processing and manufacturing capabilities and infrastructure, all of which could lead to reduced environmental impacts from the NZ built environment and financial and societal rewards.

10 Conclusions

*The following conclusions are drawn from the whole report including those made by **Scion** in Chapter 6.*

The research modelled the performance of four similar multi-storey office buildings to investigate the influence of construction materials on life cycle energy use and global warming potential.

The model was based on an actual six-storey 4250 m^2 floor area building, with a mixed–mode ventilation system, currently under construction at University of Canterbury in Christchurch. While the actual building is being constructed in concrete, two alternative versions were designed in which the structures and finishes are predominantly steel and wood. These three designs are referred to as the Concrete, Steel and Timber buildings. A fourth building design, TimberPlus has a timber structure and uses timber wherever possible in linings, window frames, louvres and cladding.

- **What is the influence of construction materials on operational energy consumption and GWP?**

To determine the influence of construction materials on life cycle energy use and GWP, it is necessary to design comparable buildings with similar operational energy consumption in order to allow meaningful analysis of the importance of embodied energy and GWP.

The operational energy analysis showed that Concrete, Steel, Timber and TimberPlus buildings can all be designed to have low operational energy consumption (average 85 $kWh/m^2/yr$), and all within 3% of each other.

Table 10.1 shows the percentage of operational energy, initial embodied energy and maintenance related embodied energy to the total primary energy usage over the full lifetime of the buildings (all calculations from data from Table 6.6). Table 10.2 shows the percentage impact on GWP emissions (all calculations from data from Table 6.7). (Note that neither table shows transport and end-of-life).

Operation of the buildings contributed the highest percentage to total lifetime energy consumption, around 94% for the TimberPlus building but only 87% for the Steel building. This result is greatly influenced by the long 60 year lifetime of the buildings, as well as the relatively large building size with high energy requirements.

Even lower operational energy consumption could be achieved by using greater amounts of insulation and thermal mass in each of the buildings. Concrete is the traditional material used for thermal mass, but thermal mass can also be provided in the Timber buildings or in the Steel building by using exposed wood surfaces as thermal mass or by using Phase Change Materials in the wall and ceiling linings.

Table 10.1: Percentage of operational, initial embodied and maintenance related embodied energy to total energy over the full lifetime of the buildings[13].

	Concrete	Steel	Timber	Timber Plus
Operational energy to total lifetime energy (%)	89	87	91	94
Initial embodied energy to total lifetime energy (%)	9	11	7	5
Maintenance related embodied energy to total lifetime energy (%)	1	1	1	1

Table 10.2: Percentage of operational GWP, initial embodied GWP and maintenance related embodied GWP to total GWP emissions over the full lifetime of the buildings[14].

	Concrete	Steel	Timber	Timber Plus
Operational GWP to total lifetime GWP (%)	72	73	86	95
Initial embodied GWP to total lifetime GWP (%)	23	23	16	11
Maintenance related embodied GWP to total lifetime GWP (%)	2	2	2	2

Even though the total operational energy consumption is similar in all buildings, the relative amounts of energy used for heating and cooling can be different, depending on the different thermal envelopes and the relative amount of thermal mass in each building.

The trends for energy consumption also apply to GWP arising from the operation of the buildings. Small variations are seen due to the primary energy mix and the manufacturing of some materials, such as concrete, which result in the chemical emission of CO_2.

- **What is the influence of construction materials on the initial embodied energy and GWP of buildings?**

The importance of the assumptions made in an LCA study as to what happens to building materials on deconstruction of the buildings after 60 years has a significant impact on the GWP, as timber and timber products have the ability to sequester carbon for long periods.

Assuming all deconstruction materials are landfilled, Tables 10.1 and 10.2 show that the Steel building has the greatest embodied energy (11%) and GWP contributions (23%), mainly caused by the large quantity of structural steel, which has a high embodied energy and GWP.

The TimberPlus building has the relatively lowest overall embodied energy (5%) and GWP (11%) contributions because it contains less aluminium and steel compared to the other

[13] This table does not show percentages for transport or end-of-life energy – hence, figures do not necessarily total to 100%.

[14] Note that this table does not show percentage contributions from GWP due to transport, end-of-life or carbon storage. The apparent anomaly of the emissions from operational, initial embodied and maintenance adding up to more than 100% is offset by carbon storage in the timber materials in the landfill.

building types, instead substituting timber-based products, such as Western Red Cedar louvres and pine cladding.

The main impact contributors for all building in terms of building components were those which contained relatively large quantities of aluminium (louvres and windows) and steel (structure).

However, the above analysis refers to a scenario where all the demolition materials are placed in landfill at the end of the 60 year lifetime of the building (and some of the materials are considered to decompose to methane which is released back to the atmosphere).

A very different result is seen where materials are either recycled or emissions of gases back to the atmosphere at the end-of-life are prevented or those gases are used to displace the use of other fossil fuels.

- **What is the influence of construction materials on the maintenance related embodied energy and GWP of buildings?**

Maintenance related embodied energy and GWP of the buildings over the 60 year lifetime contributed relatively minor environmental impacts compared to the initial embodied energy and GWP (building maintenance contributes only around 1 – 2 % to the total impacts (Tables 10.1 and 10.2) and between 12 % (Steel building) and 21 % (TimberPlus) of initial embodied energy). However, there were noticeable differences, in maintenance impacts, between building types and building components.

The Steel building had the greatest maintenance related impacts, whereas TimberPlus had the smallest. Fewer materials were required to maintain the TimberPlus building. Western red cedar, which lasts 60+ years, was used for louvres, balustrades, and reveals. These structures do not require replacement, resulting in a reduced overall impact for the TimberPlus building.

The building components that required the most maintenance, with the largest contribution to total maintenance related impact, were the windows. This is indicative of the large quantity of aluminium required in the maintenance of the frames. The exception is TimberPlus which had the lowest impact because the aluminium components of the windows were replaced with Western Red Cedar.

A well designed and constructed building, with low maintenance related embodied energy will decreases the overall life cycle impacts.

- **How does the choice of finishing materials affect the life-cycle energy use and GHG emissions?**

Comparing the Timber with the TimberPlus building shows that a significant reduction in embodied energy and embodied GHG emissions can be achieved by increasing the amount of wood and wood products in the building envelope. The largest benefit comes from replacing aluminium with wood in the window frames and the sun louvres.

A similar benefit would accrue if a large amount of timber finishing materials were used in the Concrete and Steel buildings.

Further increasing the use of timber throughout any of the buildings, for example in ceilings and interior walls, as insulation and floors, would reduce embodied energy and GHG emissions even more.

- **What impact does the end-of-life disposal of materials have on energy consumption and GWP?**

The end-of-life disposal of materials (with a number of feasible scenarios) has a significant impact on full life cycle energy consumption and GWP.

Scion proposed two end-of-life scenarios; landfilling (creating carbon storage) and material reutilisation, the latter combusting wood for energy recovery, and recycling concrete and steel. The Discussion in Section 9.5 proposes a different end-of-life scenario, where the assumption is that all carbon sequestered in wood products is retained in perpetuity.

The Scion results show a variation in end-of-life impact between landfilling and material reutilisation. Reutilisation resulted in a reduction in total energy consumption in all buildings when compared to the landfill scenario. The reutilisation scenario showed similar benefits for GWP for the Concrete and Steel buildings; however, the Timber and TimberPlus buildings showed a slight increase in total GWP (results for the two scenarios were very close, so that no firm conclusion can be made, other than that both scenarios result in a negative end-of-life GWP figure, which reduces the total life cycle GWP).

Material reutilisation enabled a significant recovery of energy and reduction in GWP for all building types. Material reutilisation recovered a proportion of the embodied energy of the wood that would otherwise be wasted if the wood was landfilled.

The building with the largest energy recovery and GWP reduction was the TimberPlus building, as this building is composed largely from wooden materials that can be combusted for energy recovery. The Steel building also had a significant reduction when the structural steel was recycled, as production of primary steel is avoided; however, the reduction is still less than recovering energy from combusting wood in the TimberPlus building.

Recycling the steel and concrete in the reutilisation scenario would be more beneficial than simply landfilling these materials because this displaces the need to use new primary materials with high initial embodied energy and GWP.

In summary, reutilisation shows clear benefits for the Steel building. The Concrete building has energy and GWP benefits from reutilisation, though they are small enough to be affected by changes in transport distances. Both scenarios result in end of life GWP reductions for the Timber and TimberPlus buildings, however the reutilisation scenario shows the additional benefit of energy recovery and displacement of fossil fuels.

The landfilling scenario presented above is greatly influenced by the assumption that 18% of timber materials decompose within 46 years of burial, methane is released and only 42% of the methane is captured (after this time there is no further significant amount of carbon released). Landfilling will become an even more beneficial option from a GHG emissions viewpoint as modern and future landfills are better constructed and managed to capture and utilise any methane generated by decomposition. (However, see the next question with regard to multiple environmental impacts).

A third end-of-life scenario (see Section 9.5) shows that if the assumption is made that 100% of the carbon in timber and timber products is permanently stored – equivalent to carbon being permanently removed from the atmosphere - then there is a significantly larger reduction in GWP for the Timber and TimberPlus buildings.

Under this scenario, considering only the impact of the materials over the life cycle of the buildings, net GWP emissions for the Timber building are around only 10% of those for the Concrete and the Steel building. This is because the carbon stored in the wood-based building materials balances out much of the GWP of the materials emitted in the manufacture of all the other materials in the building.

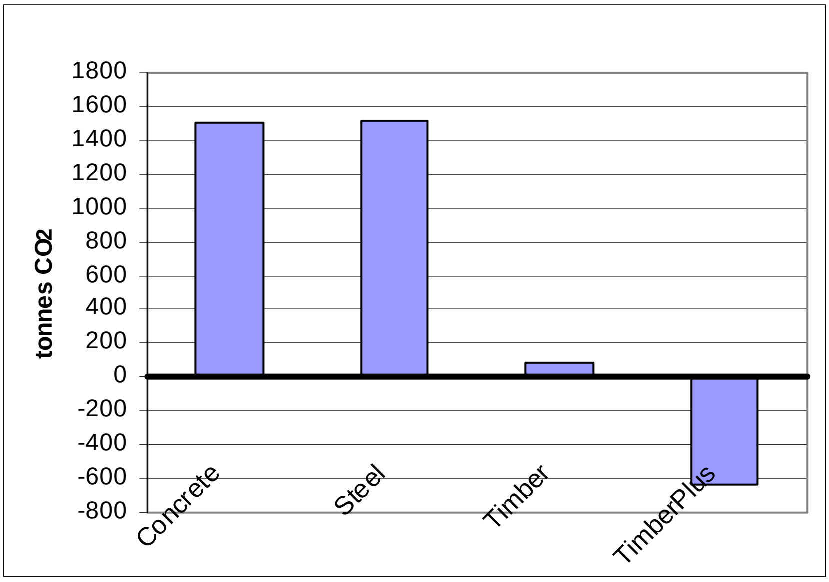

Figure 10.1. (Figure 9.2 reproduced) Net GWP emissions for the materials in the four buildings, assuming permanent storage of carbon in wood products. Data from GWP coefficients in Table 9.3 .

For the TimberPlus building, there is an even more noticeable impact - net storage of carbon, over 630 tonnes of CO_2 equivalent. The storage of carbon more than cancels out all the greenhouse gases emitted in the manufacturing process of all the other building materials.

As shown in Figure 10.2, under this permanent carbon storage scenario, the Timber and TimberPlus buildings have significantly lower net emissions over the full 60 year life-cycle of the buildings (data from Table 6.9 and Table 9.3) compared to either conventional, present-day landfilling or material reutilisation and recycling.

This storage of carbon would allow the TimberPlus building to operate for the first 12 years as a 'carbon neutral' building with no net emission of CO_2.

Net storage of carbon in wood products is consistent with the idea of 'regenerative building' where the built environment positively repairs the damage of previous generations.

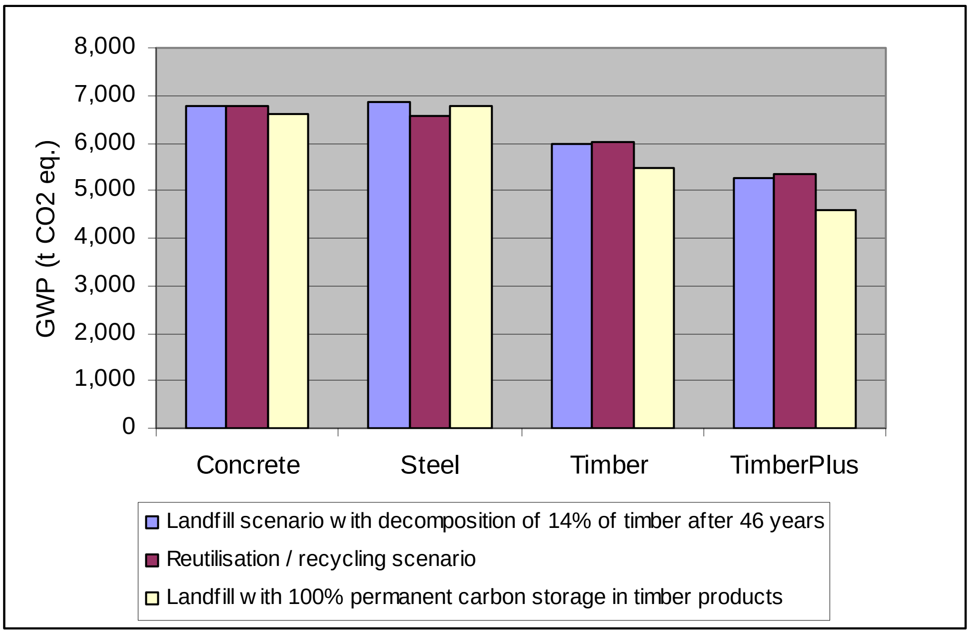

Figure 10.2. Net lifecycle GWP emissions for the four buildings showing comparison of different end-of-life scenarios.

- **How important is the choice of indicators for an assessment?**

The comparison between the two end-of-life scenarios in Chapter 6 shows that conclusions based on a single indicator could lead to unintended outcomes. Using the TimberPlus building as an example, the results of the landfilling scenario would be slightly better in terms of climate change. However, looking at the energy results alongside the global warming potential results, the reutilisation scenario shows an energy reutilisation benefit, as well as still being beneficial to climate change. Therefore, the use of multiple indicators is necessary to inform the environmental decision-making processes.

- **What is the ranking of the buildings in terms of environmental impacts?**

Initial embodied energy of materials (From Table 6.6)	Best (least embodied energy)	**TimberPlus**	↓
		Timber	
		Concrete	
	Worst (most embodied energy)	Steel	
Initial embodied CO_2-eq. of materials (From Table 6.7)	Best (lowest GWP emissions)	**TimberPlus**	↓
		Timber	
		Concrete	
	Worst (highest GWP emissions)	Steel	
Total primary energy use of building over full lifecycle - landfill scenario (From Table 6.6)	Best (least total energy used)	**TimberPlus**	↓
		Concrete	
		Timber	
	Worst (most total energy used)	Steel	
Total GWP emissions of building over full lifecycle - landfill scenario (From Table 6.7)	Best (least total GWP emissions)	**TimberPlus**	↓
		Timber	
		Concrete	
	Worst (most total GWP emissions)	Steel	
Total GWP emissions of building over full lifecycle - reutilisation scenario (From Table 6.11)	Best (least total GWP emissions)	**TimberPlus**	↓
		Timber	
		Steel	
	Worst (most total GWP emissions)	Concrete	

- **How important is the choice of energy and GWP data-set coefficients on LCA results?**

The importance of the choice of energy and GWP data-set coefficients is significant.

This is because the embodied energy and GWP of the various building materials – two of the most important environmental impacts assessed by LCA - are calculated by multiplying the quantities of materials in each building by an appropriate embodied energy or GWP coefficient.

As noted earlier (Section 9.4.3), due to the lack of locally produced and specific data for building materials, a number of previous studies in New Zealand have been based on European industry and energy data sets. However, processes, manufacturing and energy sources in NZ - with a significant proportion of renewable energy generation being fed into the NZ energy mix and wood processors, in particular, utilising locally produced biomass energy – are often very different to those found in Europe and, thus, coefficients can be very different.

The recent study "Life Cycle Assessment: Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand" (Nebel et al., 2009) has addressed some of the issues and produced a limited data set for the major building materials in NZ (see also Section 6.3.2.3.) This new NZ-specific data set shows that in comparison with one of the most widely used data sets in Europe (Gabi 4.3), there are major differences in coefficients for aluminium, steel and engineered wood products, such as LVL and plywood.

The new data set now derives a GWP coefficient for LVL produced in NZ of 0.377 kg CO_2 eq., which is significantly less than in previous studies. However, this figure is still based on Glulam (a similar laminated timber product) derived from European industry data, with some significant adaptions made to recognise NZ conditions.

Nelson Pine Industries Limited, a NZ-based producer of LVL, has undertaken extensive work to calculate a GWP coefficient for its LVL. Nelson Pine use a significant amount of biomass energy. When this biomass is recognised as a renewable energy source, they have calculated a GWP coefficient for LVL of 0.206 kg CO_2 eq. This is finished LVL product out-the-gate.

Furthermore, Nelson Pine believe that planned improvements in the production process could drop this figure to under 0.174 kg CO_2 eq.

- **Does the NZ Green Building Council Green Star Office rating tool capture the full environmental impacts of energy consumption and GWP and does the rating tool recognise the benefits of reutilising all materials?**

There are clear differences in the results of environmental impacts for both energy usage and GWP between assessments based on the Green Star rating tool and the LCA methodology. The results of both tools were not consistent and it is obvious that the recycling content of steel and concrete drive the material related results in Green Star. The reutilisation scenario in the LCA study showed that there are environmental benefits related to the energy use of post-consumer timber, especially through thermal treatment (burning to recover energy and displace other carbon based fossil fuels). This can not be accommodated for in the Green Star assessment tool.

The Green Star Office rating tool does not take the amount of timber used in a building into account. The LCA process showed a clear difference between the Timber and the TimberPlus building; however, both have the same results in the Green Star assessment.

The higher weighting of energy (25 %) than materials (10 %) for the single score of the Green Star rating is consistent with the LCA study which showed that operational energy use dominates the results over the whole life cycle.

- **Is it possible to construct a multi-storey building in Timber?**

A considerable and growing volume of research and expertise in the design of timber structures and buildings, aided by advances in engineered timber products and associated industry developments, supports the proposal that the Timber building designs in this report could be built right now.

The performance-based NZ Building codes should not provide any ‘roadblocks’. Design features of the Timber buildings can address and allay all concerns over seismic, fire and noise constraints and research is on-going.

- **What is the comparison in construction time between construction of a timber multi-storey building and equivalent conventional concrete or steel designs?**

A direct comparison between construction times shows that with a large amount of off-site prefabrication, all four buildings can be erected in less than 70 days.

- **Is it feasible and practical to increase the use (amount) of timber in multi-storey buildings?**

Today's design, engineering and construction methods show that it is entirely feasible to use timber as the main structural material for multi-storey buildings. Current research strongly indicates that an innovative post-tensioning alternative timber design to conventional concrete and steel designs is a viable and realistic proposition.

It is clearly feasible to increase the amount of timber used in the architecture of multi-storey buildings, both externally and internally. The replacement of conventional aluminium windows and louvres with equivalent timber components significantly reduces the total lifetime energy use and GWP of a building.

No building will be built exclusively of only one material - concrete, steel or timber. Buildings which combine the benefits of mixed materials – hybrid designs – such as concrete for thermal mass and timber for structural members and architectural features offer the prospect of buildings with the lowest overall environmental impacts.

This report shows that it is possible to source all timber from certified sustainable forests and processing systems and that the availability of certified timber is increasing rapidly worldwide. Furthermore, there are many timber treatments available on the market today which do not use CCA treatments and provide timber products with durability to outlast the 60 year lifetime of a typical multi-storey building.

- **Is there a problem with either reutilising or disposing of treated timber at the end-of-life of a timber building?**

Modern timber preservation techniques do not need to employ CCA treatments. Future timber buildings will not need to use CCA treated timber.

At present, at the end-of-life, most treated timber is landfilled. Modern landfills are designed to eliminate the release of harmful products of gradual decomposition or leaching. Also, research is developing methods for the removal of treatments from timber products, thus rendering it safe for recycling, landfill disposal or incineration without the use of complex filtration systems.

Treated timber products can be recycled into particleboard, chipboard and orientated strand board or incorporated into wood-plastic and wood-cement composites.

There are no facilities currently available in NZ for burning treated timber for energy production. Research and advances in gasification and pyrolysis may provide thermal treatment options in the future.

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Appendix A: Material quantities of each building type

Legend:

C	Concrete in;
R/S	Reinforcing Steel in;
S/S	Structural Steel in;
S	Other Steel in;
S/G	Galvanized Steel
G	Glass in;
T	Timber in;
LVL	LVL
C	Cedar
MDF	MDF
Al	Aluminium in;
Gib	Plasterboard to;
P	Paint to;
FC	Particleboard/fibreboard to;
In	Insulation to;

C O N C R E T E   B U I L D I N G

		m	m2	workings		m3	density	**tonnes**
	Foundations							
C	Beam Foundations	69		1.2 x 0.6	49.68			
		37		1.5 x 1.4	77.70	127.38	2.31	**294.25**
R/S	Beam Foundations	69						
		37		106			0.046	**4.88**
C	Raft Foundations		71	0.3	21.30			
			17	0.3	5.10	26.40	2.31	**60.98**
R/S	Raft Foundations		71					
			17	88			0.04	**3.52**
	Ground Floor Slabs							
C	Ground Floor Slabs		72	0.3	21.60			
			725	0.2	145.00	166.60	2.31	**384.85**
R/S	Ground Floor Slabs		72					
			725	797			0.002273	**1.81**
	Suspended floors							
C	Suspended Floor Slabs		2574	0.09	231.66			
			1046	0.09	94.14			
			645	0.065	41.93			
			41	0.14	5.74	373.47	2.31	**862.70**
R/S	Suspended Floor Slabs		2574					
			1046					
			645					
			41	4306			0.002273	**9.79**
C	Dycore units		2574	0.454	1168.60			
			1046	0.27	282.42			**1,451.02**
	Structure:							
SS	Portals							**16.66**
C	Columns	72		0.4 x 0.8	23.04			
		269		0.4 x 0.5	53.80	76.84	2.31	**177.50**
R/S	Columns	72						
		269		341			0.03	**10.23**
C	Beams	248		0.4 x 0.8	79.36			
		790		0.4 x 0.6	189.60			
		209		0.3 x 0.51	31.98			
		60		0.3 x 0.51	9.18	310.12	2.31	**716.37**
R/S	Beams	248						
		790						
		209						
		60		1307			0.015	**19.61**
C	Walls		349	0.3	104.70			
			1540	0.26	400.40			
			95	0.2	19.00			
			164	0.2	32.80	556.90	2.31	**1,286.44**
R/S	Walls		349	0.03	10.47			
			1540	0.03	46.20			
			95	0.015	1.43			
			164	0.015	2.46			**60.56**
	Stairs							
C	Stairs	27			1.62	43.74	2.31	**101.04**
R/S	Stairs	27			0.15			**4.03**
G	Balustrading	27	45.9				0.0375	**1.72**
	Roof							
S	Pant_Room_Wall Cladding		241				0.00751	**1.81**
S	Roof Cladding		445				0.00751	**3.34**
S	Spouting	36		0.25 x 0.3	0.02			
		80		0.15 x 0.175	0.03	0.05	7.85	**0.39**
S	Downpipes	158		150 dia		0.04	7.85	**0.31**
T	Roof Framing	2.6	445					
			409	2220.4	150 x 50	16.65	0.506	**8.43**
T	Plywood Roofs		409				0.01	**4.09**
	Exterior walls							
S	Exterior Wall Framing	3.5	518					
			241	2656.5	92 x 1.15		0.001523	**4.05**
S	Exterior cavity battens	1.8	518	932.4			0.000601	**0.56**
P	Exterior Walls		518					**0.06**
FC	Exotec fibrecement walls		518	Under windows on south east and north west				
			643	Along corridor	1161.00		0.0135	**15.67**
In	Walls - R2.6		518	Under windows on south east and north west				
			643	Along corridor	1161.00			**1.93**
Gib	Walls - 13 Standard		518	Envelope			0.0087	**4.51**

T	Soffit Framing	3.8	87	330.6	75 x 50	1.24	0.506	**0.63**
FC	Vitra fibrecement soffits		87				0.0135	**1.17**
P	Exterior Soffits		87					**0.01**
In	Polystyrene	Thermon	1540					**2.31**
	Windows							
G	Windows		1381					
			72		1453.00		0.03095	**44.97**
T	Window reveals	496			400 x 25	4.96	0.506	**2.51**
Al	Windows	2418		0.5	1209.00		0.005366	**6.49**
	Doors							
G	Doors	6	11				0.03095	**0.34**
T	Doors	69					0.029	**2.00**
P	Doors	69	216					**0.02**
Al	Doors	51		0.5	25.50		0.005366	**0.14**
	Interior wall							
S	Interior Wall Framing	3.5	1466					
			643	7381.5	92 x 1.15		0.001523	**11.24**
Gib	Walls - 13 Standard		643	Interior			0.0087	**5.59**
Gib	Walls - 13 Fyreline		2932	Interior			0.0098	**28.73**
P	Interior Walls		518					
			2932					
			1286					
			840		5576.00			**0.60**
In	Walls - acoustic		1466					**2.05**
	Ceiling							
In	Ceilings		445					
	Exposed to the outside		409					
			60		914.00			**1.37**
Fb/C	Mineral fibre ceiling tiles		3660					
			685		4345.00		0.0045	**19.55**
	Louvers							
Al	Louvres	2903		0.7	2032.10		0.013415	**27.26**

CONCRETE BUILDING MAINTENANCE

	Stairs	**Lifetime**	# of replacements	Mass of replacements (tonnes)	Reference
C	Stairs	**50**	0.2	20.21	Kirk et al. 1995
R/S	Stairs	**50**	0.2	0.81	Kirk et al. 1995
G	Balustrading	**40**	0.5	0.86	Kirk et al. 1995
	Roof				
S	Pant_Room_Wall Cladding	**40**	0.5	0.90	Szalay 2006
S	Roof Cladding	**40**	0.5	1.67	Szalay 2006
S	Spouting	**40**	0.5	0.20	Kirk et al. 1995
S	Downpipes	**40**	0.5	0.16	Kirk et al. 1995
	Exterior walls				
S	Exterior cavity battens	**40**	0.5	0.28	Szalay 2006
P	Exterior Walls	**8**	6.5	0.36	Szalay 2006
FC	Exotec fibrecement walls	**50**	0.2	3.13	Szalay 2006
Gib	Walls - 13 Standard	**40**	0.5	2.25	Szalay 2006
FC	Vitra fibrecement soffits	**40**	0.5	0.59	Szalay 2006
P	Exterior Soffits	**8**	6.5	0.06	Szalay 2006
	Windows				
G	Windows	**40**	0.5	22.49	Szalay 2006
T	Window reveals	**40**	0.5	1.25	Szalay 2006
Al	Windows	**40**	0.5	3.24	Szalay 2006
	Doors				
G	Doors	**40**	0.5	0.17	Szalay 2006
T	Doors	**40**	0.5	1.00	Szalay 2006
P	Doors	**8**	6.5	0.15	Szalay 2006
Al	Doors	**40**	0.5	0.07	Szalay 2006
	Interior wall				
Gib	Walls - 13 Standard	**40**	0.5	2.80	Szalay 2006
Gib	Walls - 13 Fyreline	**40**	0.5	14.37	Szalay 2006
P	Interior Walls	**8**	6.5	3.93	Szalay 2006
	Ceiling				
Fb/C	Mineral fibre ceiling tiles	**40**	0.5	9.78	Assumption

S T E E L   B U I L D I N G

		m	m2	workings		m3	density	**tonnes**
Foundations								
C	Beam Foundations	69		1.2 x 0.6	49.68			
		37		1.5 x 1.4	77.70	127.38	2.31	**294.25**
R/S	Beam Foundations	69						
		37			106.00		0.046	**4.88**
C	Raft Foundations		71	0.3	21.30			
			17	0.3	5.10	26.40	2.31	**60.98**
R/S	Raft Foundations		71					
			17		88.00		0.04	**3.52**
C	Pad Foundations	6		0.4 x 0.2	0.19	0.19	2.31	**0.44**
R/S	Pad Foundations	6		0.4 x 0.2	0.19		0.05	**0.01**
Ground Floor Slabs								
C	Ground Floor Slabs		72	0.3	21.60			
			725	0.2	145.00	166.60	2.31	**384.85**
R/S	Ground Floor Slabs		72					
			725		797.00		0.002273	**1.81**
Suspended floors								
C	Suspended Floor Slabs		4304	0.15	645.60	645.60	2.31	**1,491.34**
R/S	Suspended Floor Slabs		4304				0.002273	**9.78**
S/G	Comflor		4304				0.0115	**49.50**
Stairs								
C	Stairs	27			1.62	43.74	2.31	**101.04**
R/S	Stairs	27			0.15			**4.03**
G	Balustrading	27	45.9				0.0375	**1.72**
Structure:								
S/S	Portals			Plantroom				**15.66**
S/S	Columns							**69.66**
S/S	Beams							**138.20**
S/S	Braces							**22.82**
S/S	Plates and Cleats							**20.00**
Exterior walls								
S	Wall Cladding		1808	Cladding			0.00751	**13.58**
S/G	Exterior Wall Framing	3.5	1808					
			241					
			30	7276.5	92 x 1.15		0.001523	**11.08**
S/G	Exterior Cavity Battens	1.8	1808					
			65					
			30	3425.4			0.000601	**2.06**
P	Exterior Walls		**30**					**0.003**
FC	Exotec fibrecement walls		30	SW_Facade			0.0135	**0.41**
In	Walls - R2.6		1808					
			164					
			843					
			852		**3667.00**			**6.11**
Gib	Walls - 13 Standard		1808	Exterior walls			0.0087	**15.73**
S	Parapet Framing	3.5	65	227.5	92 x 1.15		0.001523	**0.35**
FC	Exotec fibrecement parapet		65				0.0135	**0.88**
P	Exterior Parapets		65					**0.01**
S	Soffit Framing	3.8	87	330.6			0.000601	**0.20**
FC	Vitra fibrecement soffits		87				0.0135	**1.17**
P	Exterior Soffits		87					**0.01**
Roof								
S	Wall Cladding	Plant room	241		2049.00		0.00751	**1.81**
S	Roof Cladding		445				0.00751	**3.34**
S	Spouting	36		0.25 x 0.3	0.02			
		80		0.15 x 0.175	0.03	0.05	7.85	**0.39**
S	Downpipes	158		150 dia		0.04	7.85	**0.31**
T	Roof Framing	2.6	445					
			409	2220.4	150 x 50	16.65	0.506	**8.43**
T	Plywood Roofs		409				0.01	**4.09**
Interior wall								
FC	Exotec fibrecement walls		843	Chimneys				
			852	Chimneys	1695.00		0.0135	**22.88**

S/G	Internal Wall Framing	3.5	615					
			852	5134.5	92 x 0.75		0.00104	
			164	574	150 x 0.75		0.001547	
			843	2950.5	92 x 1.15		0.001523	**10.72**
Gib	Walls - 13 Standard		328	Interior				
			843	Interior				
			852	Interior	2023.00		0.0087	**17.60**
Gib	Walls - 13 Fyreline		1230	Interior			0.0098	**12.05**
P	Interior Walls		1808					
			1230					
			328					
			1686					
			1704		6756.00			**0.73**
In	Walls - acoustic		615					**0.86**
Windows								
G	Windows		1381					
			72		1453.00		0.03095	**44.97**
T	Window reveals	496			400 x 25	4.96	0.506	**2.51**
Al	Windows	2418		0.5	1209.00		0.005366	**6.49**
Doors								
G	Doors	6	11				0.03095	**0.34**
T	Doors	69					0.029	**2.00**
P	Doors	69	216					**0.02**
Al	Doors	51		0.5	25.50		0.005366	**0.14**
Ceiling offices								
Fb/C	Mineral fibre ceiling tiles		3660					
			685		4345.00		0.0045	**19.55**
In	Ceilings		445	exposed to outside - L6 and L7 plantroom				
			409					
			60		914.00			**1.37**
Louvers								
Al	Louvres	2903		0.7	2032.10		0.013415	**27.26**

S T E E L   B U I L D I N G   M A I N T E N A N C E

Stairs		Lifetime	# of replacements	Mass of replacements (tonnes)	
C	Stairs	**50**	0.2	20.21	Kirk et al. 1995
R/S	Stairs	**50**	0.2	0.81	Kirk et al. 1995
G	Balustrading	**40**	0.5	0.86	Kirk et al. 1995
Exterior walls					
S	Wall Cladding	**30**	1	13.58	Kirk et al. 1995
S/G	Exterior Cavity Battens	**40**	0.5	1.03	Szalay 2006
P	Exterior Walls	**8**	6.5	0.02	Szalay 2006
FC	Exotec fibrecement walls	**50**	0.2	0.08	Szalay 2006
Gib	Walls - 13 Standard	**40**	0.5	7.86	Szalay 2006
S	Parapet Framing	**50**	0.2	0.07	Szalay 2006
FC	Exotec fibrecement parapet	**50**	0.2	0.18	Szalay 2006
P	Exterior Parapets	**8**	6.5	0.05	Szalay 2006
FC	Vitra fibrecement soffits	**50**	0.2	0.23	Szalay 2006
P	Exterior Soffits	**8**	6.5	0.06	Szalay 2006
Roof					
S	Wall Cladding	**40**	0.5	0.90	Szalay 2006
S	Roof Cladding	**40**	0.5	1.67	Szalay 2006
S	Spouting	**40**	0.5	0.20	Kirk et al. 1995
S	Downpipes	**40**	0.5	0.16	Kirk et al. 1995
Interior wall					
FC	Exotec fibrecement walls	**50**	0.2	4.58	Szalay 2006
Gib	Walls - 13 Standard	**40**	0.5	8.80	Szalay 2006
Gib	Walls - 13 Fyreline	**40**	0.5	6.03	Szalay 2006
P	Interior Walls	**8**	6.5	4.76	Szalay 2006
Windows					
G	Windows	**40**	0.5	22.49	Szalay 2006
T	Window reveals	**40**	0.5	1.25	Szalay 2006
Al	Windows	**40**	0.5	3.24	Szalay 2006
Doors					
G	Doors	**40**	0.5	0.17	Szalay 2006
T	Doors	**40**	0.5	1.00	Szalay 2006
P	Doors	**8**	6.5	0.15	Szalay 2006
Al	Doors	**40**	0.5	0.07	Szalay 2006
Ceiling offices					
Fb/C	Mineral fibre ceiling tiles	**40**	0.5	9.78	Assumption

T I M B E R   B U I L D I N G

		m	m2	workings		m3	density	tonnes
Foundations								
C	Beam Foundations	69		1.2 x 0.6	49.68			
		37		1.5 x 1.4	77.70	127.38	2.31	**294.25**
R/S	Beam Foundations	69						
		37		106			0.046	**4.88**
C	Raft Foundations		58	0.3	17.40			
			17	0.3	5.10	22.50	2.31	**51.98**
R/S	Raft Foundations		58					
			17	75			0.04	**3.00**
C	Foundation Pads	6		0.3 x 0.2	0.11		2.31	**0.25**
R/S	Foundation Pads	6		0.3 x 0.2	0.11		0.05	**0.01**
Ground Floor Slabs								
C	Ground Floor Slabs		72	0.25	18.00			
			725	0.2	145.00	163.00	2.31	**376.53**
R/S	Ground Floor Slabs		72					
			725	797			0.002273	**1.81**
Suspended floors								
C	Suspended Floor Slabs		4304	0.065	279.76		2.31	**646.25**
R/S	Suspended Floor Slabs		4304				0.002273	**9.78**
T	Plywood Floors		4304				0.0117	**50.36**
Stairs								
G	Balustrading	27	45.9				0.0375	**1.72**
T	Stairs	27			0.40	10.92	0.506	**5.53**
Structure:								
S/S	Posts							**2.18**
S/S	Joist hangers	900					0.00034272	**0.31**
S/S	Beam tendons	30						**0.11**
S/S	Column base shoe	18					0.0101388	**0.18**
S/S	Column base dissipater	144					0.00073631	**0.11**
S/S	Wall base dissipater	72					0.00301593	**0.22**
S/S	Wall base MacAlloy	12					0.05222898	**0.63**
LVL	Columns	430		600 x 378	97.52			
		98		500 x 378	18.52	116.05	0.506	**58.72**
LVL	Posts	140		200 x 189	5.29			
		98		160 x 126	1.98			
		123		200 x 189	4.65	11.92	0.506	**6.03**
LVL	Beams	425		600 x 378	72.29			
		442		550 x 378	91.89			
		57		450 x 252	6.46			
		80		240 x 126	2.42			
		89		200 x 126	2.24			
		52		220 x 189	2.16	177.47	0.506	**89.80**
LVL	Portals	161		360 x 189	10.95		0.506	**5.54**
LVL	Joists	1	4304	400 x 126	216.92		0.506	**109.76**
LVL	Shear Walls		581	252	146.41		0.506	**74.08**
Exterior walls								
T	Exterior Wall Framing	3.5	1572					
			30					
			241	6450.5	100 x 50	32.25	0.506	**16.32**
T	Exterior Cavity Battens	1.8	581					
			1572					
			65					
			30	4046.4	50 x 25	5.06	0.506	**2.56**
FC	Exotec fibrecement walls		581					
			1572					
			30		2183.00		0.0135	**29.47**
P	Exterior Walls		581					
			1572					
			65					
			30		2248.00			**0.24**
In	Walls - R2.6		1572					
			164					
			1685		3421.00			**5.70**
Gib	Walls - 13 Standard		1572	Extertior walls			0.0087	**13.68**
T	Parapet Framing	3.5	65	227.5	100 x 50	1.14	0.506	**0.58**
FC	Exotec fibrecement parapet		65				0.0135	**0.88**
P	Exterior Parapets		65					**0.01**
T	Soffit Framing	3.8	87	330.6	75 x 50	1.24	0.506	**0.63**
FC	Vitra fibrecement soffits		87				0.0135	**1.17**
P	Exterior Soffits		87					**0.01**

Roof

S	Wall Cladding	Plantroom	241				0.00751	**1.81**
S	Roof Cladding		445				0.00751	**3.34**
S/G	Spouting	36 80		0.25 x 0.3 0.15 x 0.175	0.02 0.03	 0.05	 7.85	 **0.39**
S/G	Downpipes	158		150 dia		0.04	7.85	**0.31**
T	Roof Framing	2.6	445 409	 2220.4	 150 x 50	 16.65	 0.506	 **8.43**
T	Plywood Roofs		409				0.01	**4.09**

Windows

G	Windows		1381 72		 1453.00		 0.03095	 **44.97**
T	Window reveals	496			400 x 25	4.96	0.506	**2.51**
Al	Windows	2418		0.5	1209.00		0.005366	**6.49**

Doors

G	Doors	6	11				0.03095	**0.34**
T	Doors	69					0.029	**2.00**
P	Doors	69	216					**0.02**
Al	Doors	51		0.5	25.50		0.005366	**0.14**

Interior wall

FC	Exotec fibrecement walls		1685	Chimneys			0.0135	**22.75**
T	Interior Wall Framing	3.5	615 1685 164	 100 x 50 300 x 50	 40.25 8.61	 48.86	 0.506	 **24.72**
Gib	Walls - 13 Standard		328 1685	Interior	 2013.00		 0.0087	 **17.51**
Gib	Walls - 13 Fyreline		1230	Interior			0.0098	**12.05**
P	Interior Walls		1572 1230 328 3370 548		 7048.00			 **0.76**
In	Walls - acoustic		615					**0.86**

Ceiling offices

Fb/C	Mineral fibre ceiling tiles		3660 685		 4345.00		 0.0045	 **19.55**
In	Ceilings		445 409 60	Exposed to outside - L6 and L7 plantroom	 914.00			 **1.37**

Louvers

Al	Louvres	2903		0.7	2032.10		0.013415	**27.26**

TIMBER BUILDING MAINTENANCE

Stairs		Lifetime	# of replacements	Mass of replacements (tonnes)	
G	Balustrading	**40**	0.5	0.86	Kirk et al. 1995
T	Stairs	**15**	3	16.58	Princeton, 2008
Exterior walls					
T	Exterior Cavity Battens	**50**	0.2	0.51	Szalay 2006
FC	Exotec fibrecement walls	**50**	0.2	5.89	Szalay 2006
P	Exterior Walls	**8**	6.5	1.58	Szalay 2006
Gib	Walls - 13 Standard	**40**	0.5	6.84	Szalay 2006
T	Parapet Framing	**50**	0.2	0.12	Szalay 2006
FC	Exotec fibrecement parapet	**50**	0.2	0.18	Szalay 2006
P	Exterior Parapets	**8**	6.5	0.05	Szalay 2006
FC	Vitra fibrecement soffits	**50**	0.2	0.23	Szalay 2006
P	Exterior Soffits	**8**	6.5	0.06	Szalay 2006
Roof					
S	Wall Cladding	**40**	0.5	0.90	Szalay 2006
S	Roof Cladding	**40**	0.5	1.67	Szalay 2006
S/G	Spouting	**40**	0.5	0.20	Kirk et al. 1995
S/G	Downpipes	**40**	0.5	0.16	Kirk et al. 1995
Windows					
G	Windows	**40**	0.5	22.49	Szalay 2006
T	Window reveals	**40**	0.5	1.25	Szalay 2006
Al	Windows	**40**	0.5	3.24	Szalay 2006
Doors					
G	Doors	**40**	0.5	0.17	Szalay 2006
T	Doors	**40**	0.5	1.00	Szalay 2006
P	Doors	**8**	6.5	0.15	Szalay 2006
Al	Doors	**40**	0.5	0.07	Szalay 2006
Interior wall					
FC	Exotec fibrecement walls	**50**	0.2	4.55	Szalay 2006
Gib	Walls - 13 Standard	**40**	0.5	8.76	Szalay 2006
Gib	Walls - 13 Fyreline	**40**	0.5	6.03	Szalay 2006
P	Interior Walls	**8**	6.5	4.96	Szalay 2006
Ceiling offices					
Fb/C	Mineral fibre ceiling tiles	**40**	0.5	9.78	Assumption

T I M B E R P L U S B U I L D I N G

		m	m2	workings		m3	density	tonnes
Foundations								
C	Beam Foundations	69		1.2 x 0.6	49.68			
		37		1.5 x 1.4	77.70	127.38	2.31	**294.25**
R/S	Beam Foundations	69						
		37		106			0.046	**4.88**
C	Raft Foundations		58	0.3	17.40			
			17	0.3	5.10	22.50	2.31	**51.98**
R/S	Raft Foundations		58					
			17	75			0.04	**3.00**
C	Foundation Pads	6		0.3 x 0.2	0.11		2.31	**0.25**
R/S	Foundation Pads	6		0.3 x 0.2	0.11		0.05	**0.01**
Ground Floor Slabs								
C	Ground Floor Slabs		72	0.25	18.00			
			725	0.2	145.00	163.00	2.31	**376.53**
R/S	Ground Floor Slabs		72					
			725	797			0.00227	**1.81**
Suspended floors								
C	Suspended Floor Slabs		4304	0.065	279.76		2.31	**646.25**
R/S	Suspended Floor Slabs		4304				0.00227	**9.78**
T	Plywood Floors		4304				0.0117	**50.36**
Stairs								
T	Stairs	27			0.40	10.92	0.506	**5.53**
T	Balustrading	27		21	50 x 25	0.71	0.506	**0.36**
Structure:								
S/S	Posts		Lift shaft					**2.18**
S/S	Joist hangers	900					0.00034	**0.31**
S/S	Beam tendons	30						**0.11**
S/S	Column base shoe	18					0.01014	**0.18**
S/S	Column base dissipater	144					0.00074	**0.11**
S/S	Wall base dissipater	72					0.00302	**0.22**
S/S	Wall base MacAlloy	12					0.05223	**0.63**
LVL	Columns	430		600 x 378	97.52			
		98		500 x 378	18.52	116.05	0.506	**58.72**
LVL	Posts	140		200 x 189	5.29			
		98		160 x 126	1.98			
		123		200 x 189	4.65	11.92	0.506	**6.03**
LVL	Beams	425		600 x 378	72.29			
		442		550 x 378	91.89			
		57		450 x 252	6.46			
		80		240 x 126	2.42			
		89		200 x 126	2.24			
		52		220 x 189	2.16	177.47	0.506	**89.80**
LVL	Portals	161		360 x 189	10.95		0.506	**5.54**
LVL	Joists	1	4304	400 x 126	216.92		0.506	**109.76**
LVL	Shear Walls		581	252	146.41		0.506	**74.08**
Roof								
S	Roof Cladding		445				0.00751	**3.34**
S/G	Spouting	36		0.25 x 0.3	0.02			
		80		0.15 x 0.175	0.03	0.05	7.85	**0.39**
S/G	Downpipes	158		150 dia		0.04	7.85	**0.31**
T	Roof Framing	2.6	445					
			409	2220.4	150 x 50	16.65	0.506	**8.43**
T	Plywood Roofs		409				0.01	**4.09**
S	Wall Cladding	Plant Room	241				0.00751	**1.81**
Exterior walls (Envelope)								
T	Exterior Wall Framing	3.5	1246					
			327					
			30					
			241	100 x 50	32.27			
			276	300 x 50	14.49			
			182	150 x 50	4.78	51.54	0.506	**26.08**
T	Exterior Cavity Battens	1.8	581					
			1246					
			327					
			65					
			182					
			30	4375.8	50 x 25	5.47	0.506	**2.77**
T	Interior Wall lining		581	10	5.81			
			1246					
			1685	12	35.17	40.98	0.506	**20.74**

T	Exterior Wall Cladding		581 1246 327 276	19	46.17		0.506	**23.36**
T	Exterior Wall Cladding		182	12	2.18		0.506	**1.11**
T	Exterior Wall Cladding		30	10	0.30		0.506	**0.15**
P	Exterior Walls		581 1246 327 65 276 182 30		2707.00			**0.29**
In	Walls - R2.6		1246 327 276 182 1685		3716.00			**6.19**
T	Soffit Framing	3.8	87	330.6	75 x 50	1.24	0.506	**0.63**
T	Soffit Lining		87	10	0.87		0.506	**0.44**
P	Exterior Soffits		87					**0.01**
T	Parapet Framing	3.5	65	227.5	100 x 50	1.14	0.506	**0.58**
T	Parapet Cladding		65	19		1.24	0.506	**0.62**
Interior wall								
T	Interior Wall Framing	3.5	238 1685	 100 x 50 300 x 50	 33.65 0.00	 33.65	 0.506	 **17.03**
T	Interior Wall Cladding		1685		20.22		0.506	**10.23**
T	Walls		377				0.056	**21.11**
P	Interior Walls		1246 327 276 182 754 476 3370 548		7179.00			**0.78**
MDF	15 MDF		327 276 182 476 82		1343.00		0.0111	**14.91**
In	Walls - acoustic		615					**0.86**
Windows								
G	Windows		949 72		1021.00		0.03095	**31.60**
T	Window reveals	496			400 x 25	4.96	0.506	**2.51**
Al	Windows	2418		0.08	193.44		0.00537	**1.04**
T	Window frames	2418			40 x 25		0.506	**1.22**
Doors								
G	Doors	6	11				0.03095	**0.34**
T	Doors	69					0.029	**2.00**
P	Doors	69	216					**0.02**
T	Door frames	51			40 x 25		0.506	**0.03**
Ceiling offices								
P	Ceilings		82					**0.01**
MDF	17 MDF ceiling tiles		4263				0.0126	**53.71**
In	Ceilings	Exposed to outside - L6 and L7 plantroom	445 409 60		914.00			**1.37**
Louvers								
T	Louvres	2903			300 x 50	43.55	0.506	**22.03**
P	Louvres	2903		0.7	2032.10			**0.22**

TIMBER PLUS BUILDING MAINTENANCE

Stairs		Lifetime	# of replacements	Mass of replacements (tonnes)	
T	Stairs	**15**	3	16.58	Princeton, 2008
Roof					
S	Roof Cladding	**40**	0.5	1.67	Szalay 2006
S/G	Spouting	**40**	0.5	0.20	Kirk et al. 1995
S/G	Downpipes	**40**	0.5	0.16	Kirk et al. 1995
S	Wall Cladding	**40**	0.5	0.90	Szalay 2006
Exterior walls (Envelope)					
T	Exterior Cavity Battens	**50**	0.2	0.55	Szalay 2006
T	Exterior Wall Cladding	**40**	0.5	11.68	Kirk et al. 1995
T	Exterior Wall Cladding	**30**	1	1.11	Kirk et al. 1995
P	Exterior Walls	**8**	6.5	1.91	Szalay 2006
T	Soffit Framing	**40**	0.5	0.31	Kirk et al. 1995
T	Soffit Lining	**40**	0.5	0.22	Kirk et al. 1995
P	Exterior Soffits	**8**	6.5	0.06	Szalay 2006
T	Parapet Framing	**40**	0.5	0.29	Kirk et al. 1995
Interior wall					
T	Interior Wall Cladding	**30**	1	10.23	Kirk et al. 1995
P	Interior Walls	**8**	6.5	5.06	Szalay 2006
MDF	15 MDF	**40**	0.5	7.45	Princeton, 2008
Windows					
G	Windows	**40**	0.5	15.80	Szalay 2006
Al	Windows	**40**	0.5	0.52	Szalay 2006
T	Window frames	**40**	0.5	0.61	Szalay 2006
Doors					
G	Doors	**40**	0.5	0.17	Szalay 2006
T	Doors	**40**	0.5	1.00	Szalay 2006
P	Doors	**8**	6.5	0.15	Szalay 2006
T	Door frames	**40**	0.5	0.01	Szalay 2006
Ceiling offices					
P	Ceilings	**8**	6.5	0.06	Szalay 2006
MDF	17 MDF ceiling tiles	**40**	0.5	26.86	Princeton, 2008
Louvers					
P	Louvres	**8**	6.5	1.43	Szalay 2006

Appendix B. Life times of building materials

From "Life Cycle Costing for Design Professionals", 2.nd Ed. Kirk et al. 1995	
Material	Useful Life
Balustrading (glass) ("Balcony Walls and Handrails - Glass Panels")	40
Pre-cast Concrete Stairs	50
Steel stairs	40
Cedar/Redwood siding (cladding)	40
Plywood Siding	30
Corrugated Metal Deck (comflor)	30
Metal soffits	40
Cast iron roof drains	40
Exterior metal panels	30+

From Princeton University Design Standards Manual (Princeton 2008)	
Material	Useful life
Aluminium Louvres	60
Plywood Panelling (plywood roofs/floors)	40
Plywood siding (ext walls)	30
Stairs - pressure treated lumber	15
Wood finish carpentry/millwork (interior wood cladding)	60-80

From Exemplar House Study (Szalay 2006)	
All foundations/floor framing/wall framing/piles	Building Life
Fibre Cement Walls	50
Weatherboard/wooden panelling	40
Plasterboard lining	40
Plasterboard ceiling lining and battens	40
Steel roofing, battens, insulation	40
Interior paint	8
Exterior paint	8
Window frames and glazing	40
External doors, frames	40
Internal doors	40

Assumptions for this study	
Acoustic Ceiling Tile, Fibre Cement	40

Appendix C: Carbon release and sequestration from wood in landfill

Calculations to determine the carbon dioxide and methane release from landfill as wood decomposes

Assumed 50% of wood mass is carbon.	
So 1kg wood = 0.5 kg Carbon.	Molar mass carbon = 12 g/mol.
0.5 kg = 41.67 moles of carbon.	Molar Mass CO_2 = 44 g/mol Molar Mass CH_4 = 16 g/mol
41.67 moles of CO_2	41.6666 moles of CH_4
41.67 x 44 grams = 1833.34 grams.	41.6666 x 16 = 666.67 grams
So 1 kg wood --> 1.83 kg of CO_2	So 1 kg wood --> 0.67 kg of CH_4
Or 1 kg carbon --> 3.67 kg CO_2	Or 1 kg carbon --> 1.34kg CH_4

Appendix D: Transport scenario

Embodied energy and GWP values for transporting materials to each building location for each building type.

Building type	Building location	Energy (MJ)	GWP (kg CO_2 eq)
Concrete	Christchurch	502,770	37,305
	Wellington	450,210	33,405
	Auckland	342,150	25,393
Steel	Christchurch	461,150	34,609
	Wellington	421,841	31,690
	Auckland	316,470	23,880
Timber	Christchurch	366,700	27,196
	Wellington	255,090	18,918
	Auckland	256,110	18,994
Timber+	Christchurch	368,680	27,342
	Wellington	245,760	18,226
	Auckland	267,920	19,869

Appendix E: Letter from Holmes Consulting Limited.

HolmesConsultingGroup

STRUCTURAL AND CIVIL ENGINEERS

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CORRESPONDENCE

29 May 2008

Dr Andrew Buchanan
University of Canterbury
Private Bag 4800
CHRISTCHURCH 8140

Dear Andy

FRST TIMBER RESEARCH - BIOLOGICAL SCIENCES STEEL OPTION REVIEW

As requested, we have been through the preliminary steel design options prepared by Steel Construction NZ. We can comment as follows:-

General

The design as presented is reasonably comprehensive for a preliminary design study, and appears to address most of the main structural elements, with the exception of the roof steelwork and the foundations. That said, it is generally of a similar level to the timber alternative that we were given, so is a useful point of comparison for a preliminary estimate.

Design Issues

There are a few areas of difference that may need further consideration:-

1. The foundation design will be sufficiently different that it ought to be factored into the comparison. The timber walls are generally on the line of the basement walls which therefore provide a significant rigid foundation beam effect, spreading load to the limits of the basement. The longitudinal frames appear to be most effective on line A, and therefore immediately over the basement, while we would expect the frame on line B to take less of the seismic load. This results in a relatively modest increase in loads to the basement floor.

   Conversely the steel building is using braced frames on or near lines B and C. Single bay braced frames such as these result in large seismic axial loads to the columns and hence the potential for significantly larger foundation loads than would result from a moment frame. It is likely that there will be a need for tension piles or ground anchors with the braced frames as shown.

2. The positioning of the central braced frames is also a problem. The steel plans indicate the frames on the line of the edge of the void, which results in the frames emerging in the storage spaces at Level 1. Addressing this would require a change to the architectural layout, or the braced frames need to relocate back onto line B. This would increase the size of the steel secondary members significantly, resulting in an overall increase in the weight of steel. Moreover, the braced frames on lines 1 and 9 would reduce in length, resulting in increased flexibility and heavier axial elements.

   The accompanying architectural drawings show the steel frames on Grid B, meaning that the frames will not be as presented in the sketches.

   This issue has been addressed in the timber option, which has the structure on Grid B as planned.

3. With such a reduced number of frames supporting the overall seismic load, we believe that the building may be excessively flexible. On the basis of a quick calculation, we determined an overall displacement in excess of 350mm in the worst case. Although the interstorey drifts may be within acceptable code limits, there may be significant practical issues in dealing with these displacements in the detailing of other elements.

   Normally, we would expect to see longer bracing elements in a building of this size, probably in multiple bay frames, resulting in stiffer structure with less significant uplift loads under the columns.

4. Although we have not performed any analysis, vibration of the floor should also be considered. In the case of potentially sensitive areas such as laboratory floors, lighter structural steel floors are potentially a problem (although we are not sure how this would compare for the timber option).

5. The floors are a combination of propped and unpropped construction. This is not necessarily an issue, but it should be noted that there is a time cost in dealing with this, and so some of the benefit of steel is negated by this.

6. No mention is made of the reinforcing in the concrete floor. We would normally expect to see a combination of 'ductile' mesh and/or mild steel, to provide shrinkage and thermal reinforcing, seismic diaphragm reinforcing and supplementary fire reinforcing. Given the spans of the Comfloor, the latter may govern. (Note a plan of this was referred to, but we do not have it).

7. Although the Engineer points out that the secondary beams may not require fire treatment if the slab panel method of analysis were used, this implies possible severe damage in the event of fire (even though life safety would be achieved in accordance with the Building Code). This could be a performance issue that would

be addressed with the client normally, possibly with a recommendation that fire treatment be installed to all members, even if only a boarded system.

With the notes above, we are generally satisfied that the steel design is a reasonable preliminary comparative design. The first two items are probably the most significant, and it may be suitable to simply allow a margin on the foundation design of say, 15%, in order to restore some relativity. This can only be verified by more intensive design.

Please contact the undersigned if you have further questions in regard.

Yours sincerely

John Hare
DIRECTOR

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Appendix F: Warren and Mahoney report.

Timber Plus

A review of the timber used in four alternative designs of multi-storey buildings.

A report for the University of Canterbury

Prepared by :

Iain Nicholls

Architectural Technologist

Warren and Mahoney®

New Zealand's first carboNZero[Cert] ™ certified architects

Summary of the Timber Plus Project.

The University of Canterbury has been engaged by the Ministry of Agriculture and Forestry to investigate the environmental impacts of multi-storey buildings using different construction materials.

The University have chosen to create a virtual model of a concrete framed building currently under construction. Using this model as a baseline, two further models have been developed. The first of these uses timber in ways which are traditional and accepted within the New Zealand construction industry, the second seeks to explore new methods and areas in which timber can be utilised. This second alternative model has been titled “The Timber Plus Building”.

The lifetime energy use together with the embodied energy of each building has been calculated for each of the three models and potential environmental impacts assessed wherever possible.

The Brief.

Warren and Mahoney have been asked to provide advice specifically regarding the timbers used within the Timber Plus building. This advice is to ensure that:-

- The embodied energy of the building is minimised.
- The maximum green-star rating for the building is achieved.
- The timber specified can be obtained from sustainable sources.
- The timber specified is suitable for the location and purpose.
- Timber treatments used, if any, are kept to a minimum and are environmentally preferable.
- Additional opportunities to maximise timber are identified.
- End of life disposal / re-use is achieved with minimum environmental impact.

It is acknowledged that this is a theoretical study and will only be presented as such.

Embodied Energy.

The embodied energy of an element is defined as the total amount of energy that is required to extract, transport, manufacture and construct that element. It covers the period “from cradle to gate” without taking into account end of life disposal.

For a brick this would include the energy required to extract the clay, to transport it to the brick-works, to pump the water, to mould it into shape, to fire it, to deliver it to site and to put it into place. In such an example the energy to fire the brick would stand out as a major energy input.

For a material such as timber, the embodied energy would include the energy required to harvest, to re-plant, to transport it to the saw mill, to process it and deliver the finished product to site and finally to install it. As timber requires relatively little energy to plant or to grow, transportation and milling become the key areas to examine. The timber used within a building should first and foremost be suitable for the application it is intended for and its harvesting should be carried out in a sustainable manner. Once these criteria are met products that require the least energy to deliver to site should be preferred.

Timber Treatment

The following methods of timber preservative are listed in order of preference. These preferences should be followed according to the level of protection required by the New Zealand Building Code and NZS3602.

1. Use of plantation timber which does not require treatment. The most reliable way to avoid decay is to use good quality well seasoned timbers in locations which are well protected from the elements, have good ventilation and can be readily inspected. Rot producing fungi are able to form when non-treated timber is subject to moist conditions for a prolonged period of time. (Including during construction). Selection of timber species with high natural durability increases timber life. (Refer to the following section for further information on natural durability ratings).

2. Boron Salts for H1 hazard ratings in all locations which are protected from the weather. Boron treated timber is not deemed hazardous.

3. CAF - Copper-based, chrome and arsenic-free treatments (such as Alkaline Copper Quaternary - ACQ) where the Building Code requires H3.2 and H5 hazard ratings. Note that certain metal products (including fasteners, hardware and flashing) may corrode when in direct contact with wood treated with copper-based preservatives. To prevent premature corrosion and failure it is important to follow the recommendations of the manufacturers for all metal products. CAF treated wood should be regarded as toxic waste when disposed of and should not be burnt or mulched.

4. LOSP - Light organic solvent preservatives where the Building Code requires H3.1 treatment. Note that there is an increase in VOC emissions when LOSPs are applied.

5. The use of CCA - (copper chrome arsenic treatments) is to be avoided. Arsenic is a known Carcinogen and, when absorbed into the human body significantly increases the incidence of some cancers. Arsenic can be absorbed through the skin, ingested or inhaled. In the case of CCA timber treatments people are most at risk where there is repeated hand contact combined with hand to mouth contact. For this reason CCA treated timber is not recommended for applications such as children's play equipment, work surfaces etc. In the United States and in several European countries there are restrictions / bans in place for CCA treated projects. Although the risk is widely regarded as minimal alternatives which are Arsenic free are preferred. CCA treated wood is regarded as toxic waste when disposed of and should not be mulched or burned.

Timber Durability Classes

Within New Zealand there are four durability classes. These are based on field tests of identically sized heartwood stakes with ratings as follows:-

Natural Durability Class	Heartwood Service Life (Years)		
	Fully Protected	Above Ground (Exposed)	In Ground
D1	50+	50+	25+
D2	50+	30	15 – 25
D3	50+	15	8 – 15
D4	50+	8	< 5

Timbers incorporated into the design of the Timber Plus building have the following natural durability ratings:-

Pinus Radiata	-	Non-Durable	D4
Thuja Plicata	-	Durable	D2
Picea Abies	-	Non-Durable	D4

Green Star Rating Scheme.

The New Zealand Green Building Council (NZGBC) have recently implemented a rating scheme for office buildings based largely on an existing Green Star rating scheme already successful in Australia. This scheme assesses new office buildings on areas which impact the natural environment and awards stars for areas of achievement.

The areas assessed by the NZGBC Greenstar Office Rating scheme are many and diverse, from the location of the building in relation to public transport facilities to the energy use of the building. The areas that relate to timber use within the building are more limited however and are as follows[1]:-

Ref.	Title	Aim of Credit	Credit Criteria Summary	Points Available
IEQ-13	Volatile Organic Compounds	To encourage and recognise projects that reduce the detrimental impact on occupant health from finishes emitting internal air pollutants	Up to three points are awarded where it is demonstrated that various finishes meet the benchmarks for low Volatile Organic Compound (VOC) content. One point is achieved for each criterion below that is achieved: 95% of all painted surfaces are low-VOC paints OR no paint is used; All carpets are low-VOC OR no carpet is installed; and/or All adhesives and sealants are low VOC OR no adhesives/sealants are used.	3
IEQ-14	Formaldehyde Minimisation	To encourage and recognise projects that reduce the use of formaldehyde composite wood products in order to promote a healthy indoor environment.	One point is awarded where it is demonstrated that: All composite wood product is low emission formaldehyde; OR No composite wood product used.	1
MAT-8	Sustainable Timber	To encourage and recognise the specification of re-used timber products or timber that has been sourced from certified environmentally responsible forest management schemes.	Two points are awarded where it is demonstrated that all timber and composite timber products used in the building and construction works are required to be sourced from either a combination of the following: Post-consumer recycled timber; or Forest Stewardship Council (FSC) certified timber. Locally sourced timber should be used unless there are demonstrable benefits from importing. If the material cost of timber represents less than 0.1% of the project's total contract value then this credit is "Not Applicable".	2

Ref.	Title	Aim of Credit	Credit Criteria Summary	Points Available
Mat-12	Non-carpet floor coverings	To encourage and recognise the selection of floor coverings that are independently verified to be environmentally preferable.	One point is awarded where it can be demonstrated that 90% or more of the non-carpet floor coverings (i.e. parquet, wooden planks, laminate and linoleum) used are independently certified as having lower environmental impact than non-carpet floor coverings, as verified through a materials certification body recognised by the NZGBC (e.g. NZ Environmental Choice). If carpets are not part of the project's contract/lease then this credit is "Not Applicable".	1
Inn-1	Innovative Strategies and Technologies	To recognise the spread of innovative initiatives for commercial building applications that improve a development's environmental impact.	Up to 5 innovation points are awarded at the discretion of the NZGBC Technical Review Group, where it is demonstrated that an innovative strategy or technology has a significant environmental benefit. The application will be assessed by the NZGBC against the following criteria: Does the application have systematic, investigative and experimental activities as part of the innovation? **OR** High levels of technical risk associated with it, for the purposes of acquiring new knowledge (whether or not for a specific technical purpose) or creating a new or improved material, products, devices, processes or services? **AND** What is the environmental benefit of the innovation? More than one innovation can be submitted, however the maximum points available for any one building assessment under the Innovation category is five in total.	5
Total points achievable through wise use of timber				12

It can be seen from the above table that the Timber Plus building has the opportunity to earn 7 points as a direct result of the correct use of timber. A further award of a maximum of 5 points is potentially available due to the innovative and experimental nature of the timber structure. A 5 star NZ excellence rating requires a minimum of 60 points and a 6 star world excellence rating 75 points.

It is possible to gain one additional point through the sensitive selection of the surface finishing treatments (paints or stains). Mat-10 requires a minimum of 95% of these coatings to be low VOC ratings throughout the whole project – not just timber finishes. It is important that this potential is not compromised by the recommendations of this report, therefore we have recommended low VOC coatings wherever it is practicable, not only in the interior.

Note 1: Intumescent coatings may be required as instructed by a Fire Engineer. These coatings are not yet available in low VOC formulae and this may render the achievement of the MAT-10 credit impossible.

Note 2: There is currently no allowance made in the Greenstar rating scheme for stains or clear finishes. It is our understanding that the imminent update to the rating tool will approve stains and clear finishes that meet the requirements of the Enironmental Choice labelling scheme. Wherever we have specified clear finishes and stains these have met these requirements as far as possible.

Volatile Organic Compounds (VOCs)

Multi-layered, engineered timber products are formed using thin sheets of timber laminate bonded together with resin to form stronger sheets. In plywood each sheet is laid with the grain perpendicular to the previous sheet, whereas laminated veneer lumber (LVL) is formed from sheets laid with each grain parallel.

Medium density fibreboard (MDF) and particleboard each consist of small timber fibres bonded into sheets again using resin.

Two forms of resin are used. The most common is phenol formaldehyde. The alternative, for particularly difficult to glue species or where the more unsightly black phenolic adhesive would be disfiguring, is amino plastic. Emissions from phenol formaldehyde are significantly less than the amino plastic binders.

In concentrated amounts VOCs have been found to cause itchy eyes and breathing irritation. They are known carcinogens and it is desirable to minimise their presence within enclosed spaces. The reduction of VOC emitting substances has the additional benefit of reducing the need for costly and energy intensive ventilation systems.

There are two standards that NZ producers of ply, LVL, MDF and Particleboard are accustomed to measuring their products against:-

AS/NZS 4357.0:2005, which sets out Formaldehyde Emission classes in section 2.7.2 Table 1. (AS/NZS 2269 for plywood). The classes are as follows:-
E0 - defined as a mean emission of 0.5 mg/L.
Super E0 - defined as a mean emission of 0.3 mg/L
Although not yet defined our expectation is that the top two grades – E0 and Super E0 - should be deemed to meet the Greenstar NZ low VOC emission standard set out in IAQ-14. E1 grade would be deemed non-compliant.

The Japanese Industrial Standard JIS A5905 2003 rates the product as F followed by a certain number of stars. The more stars the lower the emissions. Again, our expectation is that the top two grades - F*** and F**** - should be deemed to meet the Greenstar NZ low VOC emission standard. The mean formaldehyde emission level of F**** is 0.3mg/l or less which is similar to formaldehyde levels found in natural wood products. F** grade would be deemed non-compliant.

A summary of formaldehyde emission standards is as follows:

Grade	Also known as	Mean	Maximum
F****	Super E0	0.3 mg/L or less	0.4 mg/L or less
F***	E0	0.5 mg/L or less	0.7 mg/L or less
F**	E1	1.5 mg/L or less	

Sustainable Timber Sources

There is a temptation for many manufacturers and suppliers to ride the green wave and to make potentially unfounded claims of their product's environmentally preferable characteristics. This means that the building professional and the general public need to have a means of benchmarking these products against others that make similar claims. Which one is genuine? Which unfounded?

Third party certification has emerged as the most trustworthy method of assessing sustainable products. In this case a supplier / forester or manufacturer would engage a third party, who stands to gain or lose nothing through a product's success or failure, to certify the product against common criteria.

There are a variety of forest management certification schemes in operation throughout the world, and some countries have multiple schemes. Each scheme constitutes a different certification 'brand name'.
Forest management certification brands are sponsored by a number of national and international organisations and producers may choose to seek multiple certifications.

The major schemes are set out below.

International Standards Organization (ISO)

The ISO 14001 standard is a generic environmental management system standard that can apply to any industry. Three commitments must be made in the framework of ISO 14001: complying with laws and regulations, continuous improvement, and prevention of pollution. Under ISO 14001, the forest manager sets the specific indicators and criteria for sustainable forest management (SFM). After that, a management system is set up in order to help move toward those goals and to monitor improvements. However, in implementing ISO 14001, there are no specific performance requirements, no assessment of chain of custody and therefore no label. A significant number of major corporations in countries such as Sweden, Finland, Canada and the US have adopted ISO 14001, sometimes in conjunction with other systems. A number of Australian forestry companies and State forest agencies have achieved ISO 14001 certification. Evidence of compliance with ISO 14000 standard - Environment management Systems is not generally regarded as sufficient proof of a product's sustainability.

Programme for Endorsement of Forest Certification (PEFC) - Including Europe, Australia, Brazil, Canada and U.S.A.

The PEFC - was created as an umbrella organisation for nationally-based certification schemes within Europe. The Scandinavian nations were early users of certification and are currently among the largest providers of wood from certified forests. Each national certification scheme within the PEFC group maintains its own standards, although they are based on a European regional initiative (called the 'Helsinki Process') which arose from the 1992 Rio Earth Summit. PEFC confers one common label on all its recognised standards. PEFC has in its membership 32 independent national forest certification systems of which 22 to date have been through a rigorous assessment process involving public consultation and the use of independent consultants to provide the assessments on which mutual recognition decisions are taken by the membership. These 22 schemes account for over 193 million hectares of certified forests producing millions of tonnes of certified timber to the market place making PEFC the world's largest certification scheme. The other national member's schemes are at various stages of development and are working towards mutual recognition under the PEFC processes.
In 2004 the Australian Forest Standard was endorsed under the PEFC scheme.

The Forest Stewardship Council (FSC) system

The Forest Stewardship Council began as an initiative of the conservation organisation World Wide Fund for Nature. It became a corporation in October 1995 and is based in Mexico. The FSC is a framework, not a single standard. All national FSC initiatives are based on a common set of principles and criteria. The FSC Corporation assesses and approves different national standards. All FSC standards use a common label. FSC-accredited certifiers work on the basis of 10 general FSC principles and 56 criteria, as well as national or regional standards where they have been developed.
Many nations have established FSC 'National Initiatives' and in Canada and the US there are several sub-regions each with an FSC standard under development. The FSC currently covers about 84 million hectares of forest worldwide So far the FSC is concentrated in a few nations, with 36% of all FSC-certified forests in Sweden, 15% in Poland, 11% in the USA and 4% in Brazil. The remaining 34% is located in smaller quantities across 50 other nations. Only 3-4% of FSC certifications are in the Asia-Pacific region. No FSC standard has yet been developed for application in Australia.
FSC have a chain of custody (CoC) certification which certifies all parties involved in handling the product.
As noted above, the FSC certification scheme is the only scheme recognised by the NZGBC for the purpose of achieving Green Star rating scheme points.

Canadian Standards Association (CSA)

The first national certification scheme in Canada was approved in 1996 under the auspices of the Canadian Standards Association (CSA). While the development of the CSA certification standard was sponsored by industrial organizations, a wide range of stakeholders were involved in the process. The Canadian Standard is based on the management principles of the ISO 14001 but goes beyond them to include specific performance goals. Third party auditing is required for certification. CSA provides for ‘chain of custody' certification for forest products originating from a certified forest, and provides for labelling. In 2006 the Canadian national sustainable forest management standard CAN/CSA Z809:2002 was endorsed by PEFC – it covers in excess of 15 million hectares.

Sustainable Forestry Initiative (SFI)

SFI, like the international non-profit Forest Stewardship Council (FSC), sets standards for sustainably harvested timber, but SFI grew out of the trade group American Forest and Paper Association (AF&PA), and its certification process has long been seen by environmental groups as less robust than FSC’s. SFI gained a new measure of independence on January 1, 2007. Responsibility for the program was previously split between the non-profit Sustainable Forestry Board and AF&PA; the multi-stakeholder Board of Directors of the Sustainable Forestry Initiative, Inc. is now the sole governing body over the SFI Standard and all aspects of the program. Of the 15 board members, five are the CEOs of non-profit environmental groups; five board members are the CEOs of forest products companies; and the remaining board members represent stakeholders from the broader forest community. SFI is based on a set of principles, objectives and performance measures. Under SFI, companies must demonstrate continuous improvement in meeting SFI's forest management objectives. The area covered by the SFI in January 2007 was over 126 million hectares.

Timber Utilised in Timber Plus Building.

INTERNAL STAIRS

Material 1:	**Plywood.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Produced to E0 standard.
Transport:	Grown / produced in New Zealand (Tokoroa and Mt Maunganui). Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	All veneer drying is from gas and all steam for log conditioning is supplied Hog Fuel (Wood Waste) and burning of the black liquor from the pulping process.
Treatment required:	Untreated.

Material 2:	**Laserframe MSG8.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Untreated wood has extremely low natural VOC emissions.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	Untreated.
Notes:	Note that there is not always sufficient supply of the widely used sizes of MSG-8 and MSG-10 timber. For a sizable project sufficient stocks should be secured early in the construction planning process.

Material 3:	**Laminated Veneer Lumber (LVL).**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Nelson Pine LVL is manufactured using phenol formaldehyde. It complies with AS/NZS 4357.0:2005 - E0 emission standard.
Transport:	Grown / processed in New Zealand. Trucked to merchants throughout the North and South islands.
Certification:	Not certified. (FSC certified LVL available from CHH Ltd.)
Available:	Nelson Pine Ltd. www.nelsonpine.co.nz
Processing Energy:	Processing plant powered with waste wood fuel.
Treatment required:	Untreated.
Finish / Maintenance:	Assuming not for stair treads as stair treads need to meet certain slip resistance ratings – rather for the handrails, balustrades and other areas of high wear. Life Expectancy as per Resene "Expected Life System Chart" - SC1 New and SC2 Repaint cosmetic only - 10yrs, - SC3 - repaint with wear and tear - 5 yrs

Paint finish

Description:	Interior timber joinery, waterborne gloss
1st coat:	NRS: Resene Quick Dry , waterborne primer / u/coat
2nd coat:	Resene Enamacryl waterborne gloss enamel
3rd coat:	Resene Enamacryl waterborne gloss enamel

System meets Green Star IEQ 13 requirements as at 15/05/08

Stain and Clear Finish

Description:	Interior timber joinery, waterborne, stained finish
1st coat:	Resene Colorwood, waterborne wood stain
2nd coat:	Resene Aquaclear, waterborne urethane
3rd coat:	Resene Aquaclear, waterborne urethane
4th coat:	Resene Aquaclear, waterborne urethane

Resene Aquaclear available in Gloss, Semi Gloss and Satin finishes

System meets Environmental Choice but not Green Star IEQ 13 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

Clear Finish only

Description:	Interior timber joinery, waterborne, stained finish
1st coat:	Resene Aquaclear, waterborne urethane
2nd coat:	Resene Aquaclear, waterborne urethane
3rd coat:	Resene Aquaclear, waterborne urethane
4th coat:	Resene Aquaclear, waterborne urethane

Resene Aquaclear available in Gloss, Semi Gloss and Satin finishes

System meets Environmental Choice but not Green Star IEQ 13 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

PLYWOOD FLOORS

Material:	**21mm thick structural plywood.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Produced to E0 standard.
Transport:	Grown / produced in New Zealand (Tokoroa and Mt Maunganui). Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	All veneer drying is from gas and all steam for log conditioning is supplied Hog Fuel (Wood Waste) and burning of the black liquor from the pulping process.
Treatment required:	Untreated.
Finish / Maintenance:	Assuming not for stair treads as stair treads need to meet certain slip resistance ratings – rather for the handrails and other areas of high wear. : Recommendation is for a "sealer coat" only : If substrate will be exposed to direct foot traffic another 3 coats of Aquaclear will be needed and life expectancy would reduce accordingly. Expect to recoat with another 1-2 coats every 2-3 years minimum.

Life Expectancy as per Resene "Expected Life System Chart" - for sealer coat only
- SC1 New and SC2 Repaint cosmetic only – 10yrs
- SC3 – repaint with wear and tear – 5 yrs

Clear finish sealer coat only

Description:	Interior timber, stains and clear finishes, waterborne clear
1st coat:	Resene Aquaclear, waterborne clear
2nd coat:	Resene Aquaclear, waterborne clear

Resene Aquaclear available in Gloss, Semi Gloss and Satin finishes -

System meets Environmental Choice but not Green Star IEQ 13 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

COLUMNS, BEAMS, JOISTS, SHEAR WALLS AND PORTALS

Material:	**Laminated Veneer Lumber (LVL).**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Nelson Pine LVL is manufactured using phenol formaldehyde. It complies with AS/NZS 4357.0:2005 - E0 emission standard.
Transport:	Grown / processed in New Zealand. Trucked to merchants throughout the North and South islands.
Certification:	Not certified. (FSC certified LVL available from CHH Ltd.)
Available:	Nelson Pine Ltd. www.nelsonpine.co.nz
Processing Energy:	Processing plant powered with waste wood fuel.
Treatment required:	Untreated.
Finish / Maintenance:	Should not be used externally or in areas which are frequently damp.

Life Expectancy as per Resene "Expected Life System Chart" - for sealer coat only

- SC1 New and SC2 Repaint cosmetic only - 10yrs
- SC3 - repaint with wear and tear - 5 yrs

Stain and clear finish

Description:	Interior timber, stains and clear finishes, waterborne stain
1st coat:	Resene Colorwood, waterborne wood stain
2nd coat:	Resene Aquaclear, waterborne urethane
3rd coat:	Resene Aquaclear, waterborne urethane
4th coat:	Resene Aquaclear, waterborne urethane

Resene Aquaclear available in Gloss, Semi Gloss and Satin finishes -

System meets Environmental Choice but not Green Star IEQ 13 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

Clear finish only

Description:	Interior timber, stains and clear finishes, waterborne clear
1st coat:	Resene Aquaclear, waterborne urethane
2nd coat:	Resene Aquaclear, waterborne urethane
3rd coat:	Resene Aquaclear, waterborne urethane

Resene Aquaclear available in Gloss, Semi Gloss and Satin finishes.

System meets Environmental Choice but not Green Star IEQ 13 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

INTERIOR WALL FRAMING

Material:	**Laserframe MSG8.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Untreated wood has extremely low natural VOC emissions. If a LOSP based preservative treatment is used there is some VOC emission soon after treatment.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the N. and S. Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	High risk areas – I.e. bathrooms, entrance vestibule etc. – H3.1 ACQ. Low risk areas – Untreated. Bottom Plate where located above concrete screed – H1.2 Boron.

INTERIOR WALL CLADDING, BATHROOMS

We note that "15mm regular MDF board" has been specified in bathroom areas. This is not at all recommended due to the low moisture resistance of MDF. Treated ply or paint finished, finger jointed timber boards would be an acceptable alternative in this location used in conjunction with an efficient ventilation system. In wet areas (showers / splashbacks etc.) ceramic tiles on a fibre cement board substrate would be recommended.

Material:	10mm thick finger jointed solid timber boards or Ply.
Species:	Pinus Radiata (plantation grown.
VOC Emissions:	Untreated wood has extremely low natural VOC emissions. Ply to be E0 standard.
Transport:	Grown / produced in New Zealand
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Treatment required:	None.
Finish / Maintenance:	Ensure timber is not in direct contact with water Life Expectancy as per Resene "Expected Life System Chart" - SC1 New and SC2 Repaint cosmetic only - 10yrs - SC3 - repaint with wear and tear - 5 yrs

Paint finish

Description:	Interior timber joinery - bathrooms, waterborne gloss
1st coat:	NRS: Resene Quick Dry, waterborne primer / u/coat
2nd coat:	Resene Enamacryl, waterborne gloss enamel
3rd coat:	Resene Enamacryl, waterborne gloss enamel

System meets Green Star IEQ 13 requirements as at 15/05/08

INTERNAL SOLID WALLS

Material:	105mm thick Leno Tec solid timber panels (Spruce).
Species:	Picea Abies.
VOC Emissions:	Emission class E1 using melamine resin. – Would not meet expected minimum requirement of Green Star Office rating tool.
Transport:	Pre-fabricated in Europe and then shipped 20,000Kms to NZ. Not practical due to large panel sizes inconsistent with containerised transport.
Certification:	FSC certified timber unavailable in NZ. PEFC certified system acceptable as proof of sustainability but inadmissible for Green Star Office credits.
Available:	Scandinavian system sourced in Finland. Would require joint venture set-up with NZ company utilising local plantation timbers due to large panel sizes and high transport costs. (N.B. without the use of large panel sizes the benefits of the system (quick and easy erection) are dramatically reduced).
Processing Energy:	Unknown.
Treatment required:	None.
Surface Finishing:	Low VOC Paint finish applied prior to delivery.
Finish / Maintenance:	Expected to exceed 60 year building life when used in a dry, ventilated indoor location. Life expectancy of coatings as per Resene "Expected Life System Chart" - SC1 New and SC2 Repaint cosmetic only - 10yrs - SC3 - repaint with wear and tear - 5 yrs

Paint finish

Description:	Interior timber surface, waterborne low sheen
1st coat:	Resene Quick Dry, waterborne primer /undercoat
2nd coat:	Resene Zylone Sheen VOC FREE, waterborne low sheen
3rd coat:	Resene Zylone Sheen VOC FREE, waterborne low sheen

System meets Green Star IEQ 13 requirements as at 15/05/08

15 MDF

Material: Medium density fibreboard (MDF).
Species: Pinus Radiata (plantation grown).
VOC Emissions: GoldenEdge MDF is manufactured using phenol formaldehyde. It is certified as complying with the Japanese Industrial Standard JIS A5905 2003 for an F**** grade MDF (also known as Super EO).
Transport: Grown / processed in New Zealand.
Available: Nelson Pine Ltd. www.nelsonpine.co.nz
Processing Energy: Processing plant powered with waste wood fuel.
Treatment required: None.
Surface Finishing: Low VOC Paint.
Finish / Maintenance: Should not be used externally or in areas which are frequently damp. Life expectancy of coatings as per Resene "Expected Life System Chart"

- SC1 New and SC2 Repaint cosmetic only - 10yrs
- SC3 - repaint with wear and tear - 5 yrs

Paint finish

Description:	Interior timber surface, waterborne low sheen
1st coat:	Resene Quick Dry, waterborne primer /undercoat
2nd coat:	Resene Zylone Sheen VOC FREE, waterborne low sheen
3rd coat:	Resene Zylone Sheen VOC FREE, waterborne low sheen

System meets Green Star IEQ 13 requirements as at 15/05/08

17 MDF CEILING TILES

Material: Medium density fibreboard (MDF).
Species: Pinus Radiata (plantation grown).
VOC Emissions: GoldenEdge MDF is manufactured using phenol formaldehyde. It is certified as complying with the Japanese Industrial Standard JIS A5905 2003 for an F**** grade MDF (also known as Super EO).
Transport: Grown / processed in New Zealand.
Available: Nelson Pine Ltd. www.nelsonpine.co.nz
Processing Energy: Processing plant powered with waste wood fuel.
Treatment required: None.
Surface Finishing: Low VOC Paint.
Finish / Maintenance: Should not be used externally or in areas which are frequently damp. Life Expectancy as per Resene "Expected Life System Chart"

- SC1 New and SC2 Repaint cosmetic only - 10yrs
- SC3 - repaint with wear and tear - 5 yrs

Paint finish

Description:	Interior timber surface, waterborne flat
1st coat:	Resene Quick Dry, waterborne primer /undercoat
2nd coat:	Resene Ceiling Paint, waterborne flat
3rd coat:	Resene Ceiling Paint, waterborne flat

System meets Green Star IEQ 13 requirements as at 15/05/08

WINDOW REVEALS

Material:	Western Red Cedar.
Species:	Thuja Plicata
VOC Emissions:	N/A External Use Only.
Transport:	Grown / processed in W.Canada. As no chemical treatment is required for this timber species it is claimed that there is a significant reduction in embodied energy which offsets the additional transport energy required to cross the Pacific.
Certification:	FSC certified timber available in NZ.
Available:	Herman Pacific Ltd. www.hermpac.co.nz
Processing Energy:	Unknown.
Treatment required:	None.
Surface Finishing:	Migrating oil stain (penetrating stain).
Finish / Maintenance:	With correct maintenance of surface finishes cedar is expected to last well in excess of the 60 year building lifespan. Note: Paint finish is preferred for timber joinery or at least a stain under the clear finish. Clear finishes alone will still allow degradation of the timber under the clear film as UV light will still penetrate the clear. Pigments in stain and paint help prevent penetration of the UV light which breaks down the timber fibres.

Paint finish

Life expectancy as per Resene "Expected Life System Chart" - paint system only

- SC1 New and SC2 Repaint cosmetic only - 10yrs
- SC3 - repaint with wear and tear - 5 yrs

Description:	Interior timber joinery, waterborne gloss
1st coat:	NRS: Resene Quick Dry, waterborne primer / undercoat
2nd coat:	Resene Enamacryl waterborne gloss enamel
3rd coat:	Resene Enamacryl waterborne gloss enamel

System meets Green Star IEQ13 requirements as at 15/05/08

Stain and Clear Finish

Life expectancy stain and clear - reapplication of clear finish to the sill areas of windows will need to be approximately every 3-4 years. Other areas, approximately 6-8 years depending on sun exposure.

Description:	Interior timber joinery, waterborne, stained finish
1st coat:	Resene Colorwood **D50a**, waterborne wood stain
2nd coat:	Resene Aquaclear **D59**, waterborne urethane
3rd coat:	Resene Aquaclear **D59**, waterborne urethane
4th coat:	Resene Aquaclear **D59**, waterborne urethane

Resene Aquaclear available in Gloss, Semi Gloss and Satin finishes -

System meets Environmental Choice but not Green Star IEQ 13 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

ROOF FRAMING

Material:	**Laserframe.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	No solvents involved in preservative treatment.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	H3.1 ACQ.
Finish / Maintenance:	Periodic inspections to ensure integrity of roof coverings.

PLYWOOD ROOFS

Material:	**Construction Plywood.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	Produced to E0 standard.
Transport:	Grown / produced in New Zealand (Tokoroa and Mt Maunganui). Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	All veneer drying is from gas and all steam for log conditioning is supplied Hog Fuel (Wood Waste) and burning of the black liquor from the pulping process.
Treatment required:	H3.1 rated ACQ.
Finish / Maintenance:	Periodic inspections to ensure integrity of roof coverings. Note that all membrane roofs must be ventilated. There is currently no NZ standard for this but a code of practice is currently being developed. When this is available it should be adhered to for the timber plus building.

PARAPET FRAMING

Material:	**Laserframe.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	No solvents involved in preservative treatment.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	H1.2 Boron.

SOFFIT FRAMING

Material:	**Laserframe.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	No solvents involved in preservative treatment.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	H1.2 Boron.

EXTERIOR WALL FRAMING

Material:	**Laserframe MSG8.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	No solvents involved in preservative treatment.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	H1.2 Boron.
Notes:	Note that there is not always sufficient supply of the widely used sizes of MSG-8 and MSG-10 timber. For a sizable project sufficient stocks should be secured early in the construction planning process.

EXTERIOR CAVITY BATTENS

Material:	**45 x 25mm Timber Battens.**
Species:	Pinus Radiata (plantation grown).
VOC Emissions:	No solvents involved in preservative treatment.
Transport:	Grown / produced in New Zealand. S. Island supplies from Nelson. N. Island supplied from Kawerau. Trucked to merchants throughout the North and South Islands.
Certification:	FSC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	100% of the heat used in drying timber at the Nelson plant is derived from wood waste. The heat used for drying at the Kawerau plant comes from the Hog Fuel (Wood Waste) and from burning the Black Liquor produced from dissolving the wood fibre in NAOH.
Treatment required:	H3.1 ACQ.

EXTERIOR WALL CLADDING

Material:	**TDA's Flatline Board Sytem.**
Species:	Pinus Radiata
Available:	Currently this is a conceptual timber cladding system developed by Australia's Timber Development Agency. It is not yet in production but is an "open-source" system which can be utilised by any cladding manufacturer. Theoretically therefore it could be manufactured in New Zealand utilising locally sourced, FSC certified timber.
Processing Energy:	N/A.
Treatment required:	H3.1 ACQ.
Surface Finishing:	Factory applied stain primer. Top coat on-site with either natural or tinted stain OR opaque paint finish.
Note:	Metal cavity batten system and metal vertical board jointers recommended by TDA research body. This system is untested in multi-storey applications and would need to be subjected to rigorous checks before it could achieve building code approval.
Finish / Maintenance	Note 1: this system would have to be assessed along with its special sealer coat - as system is new to Resene. Recommendation is written as for standard stain finish only NOT including any proprietary finish. Note 2: Stain should be applied to ALL faces of the timber prior to installation - this includes the back face. Note 3: Check manufacturer's instructions for colour restrictions on substrates. Dark colours, in both paint and stain finishes, used externally may void warranties. Note 4: Resene "Cool Colours" technology is recommended where dark colours are specified externally.

Stain Finish

Life Expectancy as per Resene "Expected Life System Chart" does not include exterior stains

- Stains need reapplication every 3-5 years to maintain their properties including, colour durablity, water-repellency and mould inhibition.
- Note there will be areas to any stained building where stain fades faster than others.

Description:	Exterior timbers, stains and clear finishes, waterborne stain
1st coat:	Resene Waterborne Woodsman, waterborne stain
2nd coat:	Resene Waterborne Woodsman, waterborne stain
3rd coat:	Apply third coat if possible after 1st summer

System meets Environmental Choice but not Green Star MAT 10 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

Paint finish

Life Expectancy as per Resene "Expected Life System Chart"

- SC1 New and SC2 Repaint cosmetic only - 10yrs
- SC3 - repaint with wear and tear - 6 yrs

Description:	Exterior timbers, waterborne satin
Surface Prep:	If needed Resene Timberlock, solvent-borne preserver/conditioner
1st coat:	Resene Quick Dry, waterborne primer / undercoat
2nd coat:	Resene Lumbersider, waterborne satin
3rd coat:	Resene Lumbersider, waterborne satin

**Alternatively for Semi Gloss finish use Sonyx 101, D30 or gloss finish use Hi Glo, D31*

System meets Environmental Choice & Green Star MAT 10 paints requirements as at 15/05/08.

EXTERIOR WALL CLADDING (CONTINUED).

Material:	**Shadowclad.**
Species:	Pinus Radiata
VOC Emissions:	N/A. Exterior cladding application.
Transport:	Grown / produced in New Zealand (Tokoroa and Mt Maunganui). Trucked to merchants throughout the North and South Islands.
Certification:	FSC CoC certified
Available:	Carter Holt Harvey Ltd. www.chh.com
Processing Energy:	All veneer drying is from gas and all steam for log conditioning is supplied Hog Fuel (Wood Waste) and burning of the black liquor from the pulping process.
Treatment required:	Pre-treated with H3.1 LOSP Azole.
Surface Finishing:	Painting with light colours will reduce the incidence of face “checking” (Face checking is caused by the normal swelling and shrinkage of wood, particularly on Northern facing elevations).
Finish / Maintenance:	Note1 : Shadowclad ply has a minimum LRV or Light Reflectance Value of 40% as set by the manufacturer. This restricts the use of dark colours or warranty will be void. Note 2: Stain should be applied to ALL faces of the timber prior to installation - this includes the back face. Note 3: Resene “Cool Colours” technology is recommended where dark colours are specified externally.

Stain Finish

Life Expectancy as per Resene “Expected Life System Chart”

- Stains need reapplication every 3-5 years to maintain their properties including, colour durablity, water-repellency and mould inhibition.
- Note there will be areas to any stained building where stain fades faster than others.

Description:	Exterior timbers, stains and clear finishes, waterborne stain
1st coat:	Resene Waterborne Woodsman, waterborne stain
2nd coat:	Resene Waterborne Woodsman, waterborne stain
3rd coat:	Apply third coat if possible after 1st summer

System meets Environmental Choice but not Green Star MAT 10 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

Paint finish

Life Expectancy as per Resene “Expected Life System Chart”

- SC1 New and SC2 Repaint cosmetic only - 10yrs
- SC3 - repaint with wear and tear - 6 yrs

Description:	Exterior timbers, waterborne satin
Surface Prep:	If needed Resene Timberlock, solvent-borne preserver/conditioner
1st coat:	NW: Resene Quick Dry, waterborne primer / undercoat
2nd coat:	Resene Lumbersider, waterborne satin
3rd coat:	Resene Lumbersider, waterborne satin

**Alternatively for Semi Gloss finish use Sonyx 101, D30 or gloss finish use Hi Glo, D31*

System meets Environmental Choice and Green Star MAT 10 Paints requirements as at 15/05/08.

LOUVRES

Material:	Western Red Cedar.
Species:	Thuja Plicata
VOC Emissions:	N/A External Use Only.
Transport:	Grown / processed in W.Canada.
Certification:	FSC certified timber available in NZ.
Available:	Herman Pacific Ltd. www.hermpac.co.nz
Processing Energy:	Unknown.
Treatment required:	None.
Surface Finishing:	Migrating oil stain (penetrating stain).
Finish / Maintenance:	With correct maintenance of surface finishes cedar is expected to last well in excess of the 60 year building lifespan. Check manufacturer's instructions for colour restrictions on substrates. Dark colours, in both paint and stain finishes, used externally may void warranties. Note 2: Stain should be applied to ALL faces of the timber prior to installation - this includes the back face. Note 3: Resene "Cool Colours" technology is recommended where dark colours are specified externally.

Stain Finish

Life Expectancy as per Resene "Expected Life System Chart" does not include exterior stains
- Stains need reapplication every 3-5 years to maintain their properties including, colour durablity, water-repellency and mould inhibition.
- Note there will be areas to any stained building where stain fades faster than others.

Description:	Exterior timbers, stains and clear finishes, waterborne stain
1st coat:	Resene Waterborne Woodsman, waterborne stain
2nd coat:	Resene Waterborne Woodsman, waterborne stain
3rd coat:	Apply third coat if possible after 1st summer

System meets Environmental Choice but not Green Star MAT 10 requirements as at 15/05/08 - as there are no allowances for stains or clear finishes currently.

Additional Opportunities.

There are a number of additional opportunities to maximise the use of timber and timber derived products within the timber plus building. We have identified the following as offering potential:-

CEILINGS:

Atkar™ Au.diPanel™ round hole perforated MDF or ply ceiling panels available from Asona Ltd. with pre-finished timber grain and decorative surfaces, IAB acoustic tissue backer and edge profiled. Manufactured in Australia.

INTERIOR WALLS:

Woodwool acoustic insulation products to reduce reverberation times within room.

INSULATION:

Insulation created from cellulose fibres could be used to insulate ceiling and external wall cavities with integral fire retardants as necessary.

FLOORS:

Linoleum sheet flooring could be used to bathroom and kitchenette areas. Linoleum is manufactured from renewable resources including wood flour, cork flour, jute, linseed oil and natural resin. The expected life span is 30 years. Available from Tarkett flooring Ltd. Manufactured in Italy.

Timber overlay flooring could be used throughout office and reception areas. FSC certified parquet flooring is available from Ekowood Ltd. The expected lifespan is 60years+ when well maintained (it can be re-sanded and re-finished up to three times) and it is warranted for 25 years. Manufactured in Malaysia from New Zealand Pinus Radiata with a sustainably sourced tropical timber wearing layer.

Wood fibre acoustic Insulation panels could be used beneath the overlay flooring to reduce inter-floor sound transmission and reduce reverberation within office areas. Sonopan insulation panels are available from Louisville Speciality Products Ltd. Manufactured in Canada.

EXTERNAL:

There is an opportunity to construct a timber deck on bearers leading up to the main entrance in place of the solid timber on slab that is currently shown. This may not increase the timber component but would reduce the concrete used in the building. Options would be:-

- Pinus Radiata decking treated to H3.2 with a copper-based chrome and arsenic-free (CAF) treatment such as ACQ (Alkaline Copper Quaternary). OR:
- NZ red beech (Nothofagus Fusca) which does not need additional chemical treatment in decking situations. H3.2 ACQ treatment to posts in contact / below ground. Red Beech could also be used as the flooring to the entrance foyer to provide a seamless entrance showcasing one of New Zealand's most beautiful timber species.

References.

1. NZGBC Green Star NZ – Office Design V1 rating tool.
2. BRANZ Bulletin 445 Feb 2004 Timber Treatment
3. New Zealand Building Code part B (Durability) and E2 (External Moisture).

Appendix A

Resene Expected Paint Systems Life Chart

Resene expected paint system life

The expected paint system life chart below indicates the expected life of a well maintained pigmented waterborne paint system applied to a properly prepared surface to the specifications of Resene before recoating is required. Well maintained means regular washing of exterior surfaces and repairing any obvious damage. See the Resene Caring for your paint finish brochure for recommended cleaning instructions.

For example:

Painting an EXTERIOR building. The concrete WALLS are to be painted and the surface condition is described as 'IDEAL' (SC1), giving the indication that 12 years could be expected provided regular washing and repairs are carried out during this time. After this the surface will require painting. The box at the bottom of this page gauges the expected surface condition at the end of the stated lifetime. The system for example should have received very little change (0) in surface cracking but it would be expected to have suffered colour change (3).

Expected paint system life

	Exterior			Interior		
	Cementitious	Metal Corrosion less than 2% of surface	Timber	Paperfaced and cloth plaster	Solid plaster	Timber
SC1	12	10	10	10	10	10
SC2	12	10	10	10	10	10
SC3	10	7	6	6	6	5
SC4	8	5	3	-	-	-

Exterior expected life figures are for vertical exposure. Surfaces less than 60° to the horizontal will have a 50% reduced life expectancy compared to the stated life expectancies above. Interior expected life figures refer only to durability characteristics of chipping, cracking, flaking, peeling and general film integrity. Colourfastness is excluded. Due to the vast range of staining and the varying effects of this on the substrate and finish it is not possible to include these factors in a general guideline.

Extreme marine environments, adhesion failure of previous coatings, substrate damage or use of solventborne products will result in reduced life expectancies. Refer Resene for assistance.

Surface conditions are defined as follows:

1. IDEAL New surface in excellent condition. No defects. Surface has not been exposed to weather.
2. GOOD Coated surfaces requiring repaint for cosmetic reasons only. Apparently sound coating protecting substrate, no paint breakdown.
3. FAIR Some substrate exposed for undetermined time due to incidence of paint breakdown - requires preparatory work and spot priming.
4. POOR Substantial areas exposed to weathering for substantial time or never painted.

Test method	Description	Exterior	Interior
AS1580 481.1.11	Chalking	2	0
AS1580 481.1.12	Colour change	3	1
AS1580 481.1.5	Gloss change	3.5	0
AS1580 481.1.8	Cracking	0	0
AS1580 481.1.10	Flaking	0	0
AS1580 481.1.2	Discoloration	4	1

Key: 0 = No change, 5 = Severe change

If in doubt about any aspect of your specification or project please contact Resene.

Appendix G: Green Star Assessment of Different Building Options – Peer Review

New Zealand Forest Research Institute Limited trading as Scion

GreenStar Assessment of Different Building Options - Peer review

July 2008

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Revision Schedule					
Rev No	Date	Description	Prepared By	Reviewed By	Approved By

New Zealand Forest Research Institute Limited trading as Scion

GreenStar Assessment of Different Building Options - Peer review

Contents

List of Tables

List of Figures

Executive Summary

A common building design has been used as a basis for comparison between four types of building construction materials. The four different types of materials under comparison included; concrete, steel, timber and timber plus (where the use of timber had been maximised). The building was based upon an existing building that had recently been constructed from concrete.

A LCA (Life Cycle Assessment) assessment has been undertaken of the different construction materials, under the single design regime using operational energy calculations and material lists developed by a quantity surveyor. The operational energy and materials aspects of the LCA assessment have also been applied to the building under the GreenStar Office Design V1 building performance rating tool. The approach of both tools is different. Whereas the LCA is based on quantified data of all materials and energy used over the life time of a building, Green Star is based on credits awarded for a number of specified criteria.

Due to the differences in the scope of both tools, the comparison was restricted to those aspects which are taken into account in both tools, *i.e.* material use and energy use. Two scenarios were assessed using the Green Star NZ Office Design V1 rating tool. A base scenario which took into account the dominant materials, i.e. timber, steel and concrete only and a recycling scenario which is similar to the reutilisation scenario in the LCA study.

Under the base scenario the results for the GreenStar NZ assessments rated the use of concrete most favourably in construction but did not separate steel, timber and timber+. Whereas LCA demonstrated clear differences in the desirability of the different materials from an energy use and global warming potential perspective with timber+ having the least sensitive environmental profile.

Under the re-utilisation scenario GreenStar NZ was unable to differentiate between concrete, timber and timber+ and rated steel as the optimal building material. Using energy use and global warming potential data LCA assessment of the same information showed timber+ as the least environmentally degrading.

To achieve very similar operational energy profiles required different design for envelope walls construction, thermal mass, and heating and cooling equipment in each of the four buildings. This fundamental variation was not able to be reflected in the GreenStar NZ self-assessments due to the limited credits assessed and resulted in skewed reporting of the ratings achieved.

The energy mix was important when considering GWP since two buildings having the same total energy might use different proportions of gas and electricity. Not all energy is equal; combustion emissions differ by energy form and the upstream, pre-combustion implications of producing and moving different energy forms can be even more significant. The energy mix is of vital importance for the GreenStar NZ rating system and significantly different mixes would have been awarded different credits under the criteria of the energy calculator. The information provided for natural gas and electricity was slightly different for the four buildings but the tool was not able to discern the mire subtle differences under the limited credits assessed.

The base building was not an office building, it was based upon the laboratory buildings for the Biological Science facilities at Canterbury University, therefore the use of the Office Design tool was of questionable value. However, in the absence of any other more appropriate tools (*i.e.* the GreenStar NZ Education tool currently under development) the study carried out has highlighted some important principles for further investigation.

There were relatively small differences between the results from base and re-utilisation scenarios. This was in part due to the limited number of credits chosen for comparison. The assumptions of no differences in inherent building characteristics for those credits not under scrutiny for each material assessed did not align with the basic premise of the GreenStar NZ rating tool which caters for fundamental differences in buildings using offsetting of credits in other categories to drive positive changes in behaviour.

There are substantial rewards under the material category of the GreenStar NZ for recycled content of steel and concrete and integrated fit out. These drivers do not account for the environmental benefits demonstrated by LCA that are not recycling driven. The presumption of GreenStar NZ and most green building rating systems is that recycled materials will automatically result in reduced environmental burdens. This is not always the case and a review of these aspects using LCA would be prudent where data and benchmarks are available.

In the long run the integration of LCA tools into whole building assessment systems will yield significant benefits, not only will it improve understanding and appropriate rewards for environmental performance, but once established future LCA will be less complex and expensive. A paradigm shift is required away from conventional wisdom and related procurement decisions toward minimisation of life cycle flows to and from nature.

1 Introduction

A common building design has been used as a basis for comparison between four types of building construction materials. The four different types of materials under comparison included; concrete, steel, timber and timber plus (where the use of timber had been maximised). The building was based upon an existing building that had recently been constructed from concrete.

1.1 Background to the Project

A LCA (Life Cycle Assessment) assessment was been undertaken of the different construction materials, under a single design regime using operational energy calculations and material lists developed by a quantity surveyor. The operational energy and materials aspects of the LCA assessment have also been applied to the GreenStar NZ Office Design V1 building rating tool.

The scope of both tools was different, hence the comparison was restricted to those aspects which were taken into account in both tools, *i.e.* material use and energy use. All features of the buildings that were not strictly material or energy use related were assumed to be identical for the different building designs.

Two scenarios were assessed using the Green Star NZ Office Design V1 rating tool. A base scenario accounted for the dominant materials, i.e. timber, steel and concrete only and a recycling scenario which is similar to the reutilisation scenario in the LCA study as follows;

Green Star Base scenario
The Green Star Base scenario took only the core materials of each building type into account as described below;

Timber building

- N/A was ticked for recycled steel and concrete content respectively although, according to the Green Star methodology, N/A can only be ticked if the material cost for steel or concrete respectively is less then 1 % of the project's total contract value. Since the Green Star Assessment was undertaken in order to assess the differences between the building materials concrete recycling was assumed for the concrete building, steel recycling for the steel building and for the timber building only the thermal utilisation of timber. This approach was taken to demonstrate the specifics of each material.
- Sustainable timber (FSC certified) was chosen for the timber option of the building.
- Operational energy figure specific to the timber building were included (73 kWh/m2/yr metered electricity and 15 kWh/m2/yr metered natural gas).
- All other assumptions were identical to the timber plus, steel and concrete buildings.

Timber plus building

- The amount of timber used cannot be accounted for in Green Star. The results for the timber plus building were therefore identical with the timber building.
- Operational energy figure specific to the timber plus building were included (70 kWh/m2/yr metered electricity and 16 kWh/m2/yr metered natural gas).
- All other assumptions were identical to the timber, steel and concrete buildings.

Concrete building

- Recycled concrete was assumed for the concrete building. The N/A option was ticked for steel and timber respectively.
- Operational energy figure specific to the concrete building were included (68 kWh/m2/yr metered electricity and 16 kWh/m2/yr metered natural gas).
- All other assumptions were the same as for steel and timber.

Steel building

- Recycled steel was assumed for the steel building. The N/A option was ticked for concrete and timber respectively.
- Operational energy figure specific to the steel building were included (70 kWh/m2/yr metered electricity and 16 kWh/m2/yr metered natural gas).
- All other assumptions were the same as for concrete and timber buildings.

Green Star Recycling Scenario

The Green Star Recycling Scenario takes recycling in all buildings into account. In order to provide a fair assessment the maximum points for each material were applied where the material had to be taken into account. This means for example that concrete in the timber building has been recycled, but on the other hand that the timber in the concrete building was FSC certified. However, if less then 1 % of the total project value is due to materials costs of steel or concrete respectively the option 'not applicable' is available.

The assumptions were as follows;

Timber building

- Concrete recycling was taken into account. The N/A option can only be ticked if the contribution of concrete is less then 1 % of the project value. For the timber building, concrete is required in the foundations. Although detailed data on the cost contribution of specific materials was not available, the contribution in terms of mass was > 1%. The recycling option was therefore assumed.
- The N/A option for steel can also be only ticked is less than 1% of the cost contribution. Because the cost contribution was not available, the decision was based on the material contribution which less then 1 % and N/A was ticked.
- Operational energy figure specific to the timber building were included (73 kWh/m2/yr metered electricity and 15 kWh/m2/yr metered natural gas).
- All other assumptions were identical with the timber plus, steel and concrete buildings.

Timber plus

- The same assumptions as for the timber building were applied.
- Operational energy figure specific to the timber plus building were included (70 kWh/m2/yr metered electricity and 16 kWh/m2/yr metered natural gas).
- All other assumptions were identical with the timber, steel and concrete buildings.

Concrete building

- The steel contribution was less then 0.5 % and consequently the N/A option was chosen.
- The cut off criteria for timber is 0.1 %. FSC certified was therefore taken into account for the steel building.
- Operational energy figure specific to the steel building were included (68 kWh/m2/yr metered electricity and 16 kWh/m2/yr metered natural gas).
- All other assumptions were identical with the timber, timber plus and steel buildings.

Steel building

- The cut off criteria for FSC certified timber is 0.1 %. FSC certified was therefore taken into account for the steel building.
- The concrete contribution was > 1 % and recycled concrete was chosen for this scenario.
- Operational energy figure specific to the steel building were included (70 kWh/m2/yr metered electricity and 16 kWh/m2/yr metered natural gas).
- All other assumptions were identical with the timber, timber plus and concrete buildings.

Using the above assumptions the project objective was to determine whether the building material (whole category) and energy (limited credits only) related credits of the GreenStar Office Design V1 building rating tool are comparable with the results of a LCA-based assessment. What follows is a synopsis of the two tools to assist with the interpretation of the results. The basis of the GreenStar NZ building performance rating tool is described initially, followed by a simple description of LCA.

1.1.1 Introduction to the GreenStar NZ Building Performance Rating Tool Framework

The inaugural GreenStar NZ building performance rating tool (Office Design V1) was introduced in New Zealand in 2007. Although there are some conceptual differences between LCA and Green Star, both tools aim to identify life cycle impacts and have the potential to minimise the environmental impacts of buildings. Both tools have in common that they take energy use and materials in to account. However, the approach of both tools is different. Whereas the LCA is based on quantified data of all materials and energy used over the life time of a building, Green Star is based on credits for a number of criteria.

A brief introduction to the Green Star NZ Office Design V1 tool is provided as background information for the gap analysis that follows.

The Green Star NZ building performance rating framework was developed by the New Zealand Green Building Council (NZGBC) and it aims to:

- Define green building by establishing a common language and standard of measurement;
- Promote integrated, whole-building design;
- Identify building life-cycle impacts;
- Raise awareness of green building benefits;
- Recognise and reward environmental leadership; and
- Transform the built environment to reduce the environmental impact of development.

(Green Star NZ Office Design V1, 2008)

The GreenStar NZ Office Design V1 tool was developed for the design stage of office buildings to evaluate the environmental initiatives and/or potential environmental impacts of commercial office base building designs (Green Star NZ Office Design V1). It has been shown that the design stage of office buildings is when the most influence can be made upon total life cycle costs.

In the Green Star NZ building performance rating tool credits are awarded for certain activities and where possible industry benchmarks are used. For example 1 point is awarded where it can be demonstrated that the percentage of all steel in the design has a post-consumer recycled content great than 60 % by mass, and 2 points for 90 % by mass. If the material cost of steel represents less than 1 % of the project's total contract value then this credit would be "not applicable". Similarly 2 points are awarded where it is demonstrated that all timber and composite timber products are either post-consumer re-used timber or FSC (Forest Stewardship Certified) timber or a combination of both. In other categories points are awarded for other categories (Figure 1-1-1).

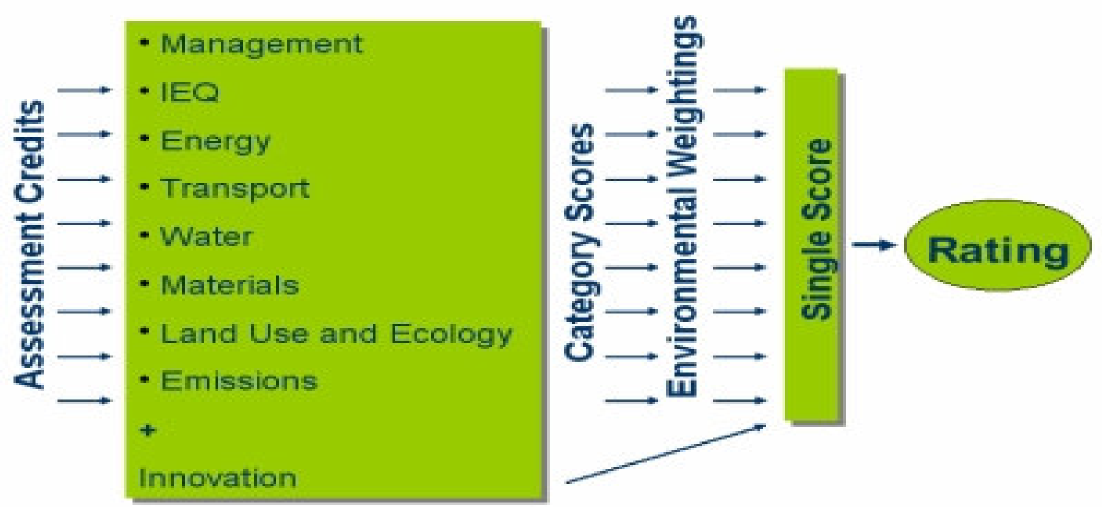

Figure 1-1-1: Generic Green Star NZ Framework (NZGBC 2008)

All points are then weighted and summarised into a single score, where materials have a contribution of 10 % to the total score whereas energy has a contribution of 25 %. For all weightings see Table 1-1.

Table 1-1-1: Weightings in Green Star tool

Management	10 %
Indoor Environmental Quality	20 %
Energy	25 %
Transport	10 %
Water	10 %
Materials	10 %
Land Use and Ecology	10 %
Emissions	5 %
Total (+ innovation)	100 %

1.1.2 Principles of Life Cycle Assessment

Materials stewardship is fundamental to sustainable development, and should provide a unifying approach to the development and implementation of policies directed at sustainable use of materials.

Life cycle assessment (LCA) is an analytical methodology that is used to quantify the environmental impacts of products, processes or services (see Figure 1-1-2 for a 'life cycle'). The construction industry can apply this methodology to deliver sustainable development through enhanced materials stewardship.

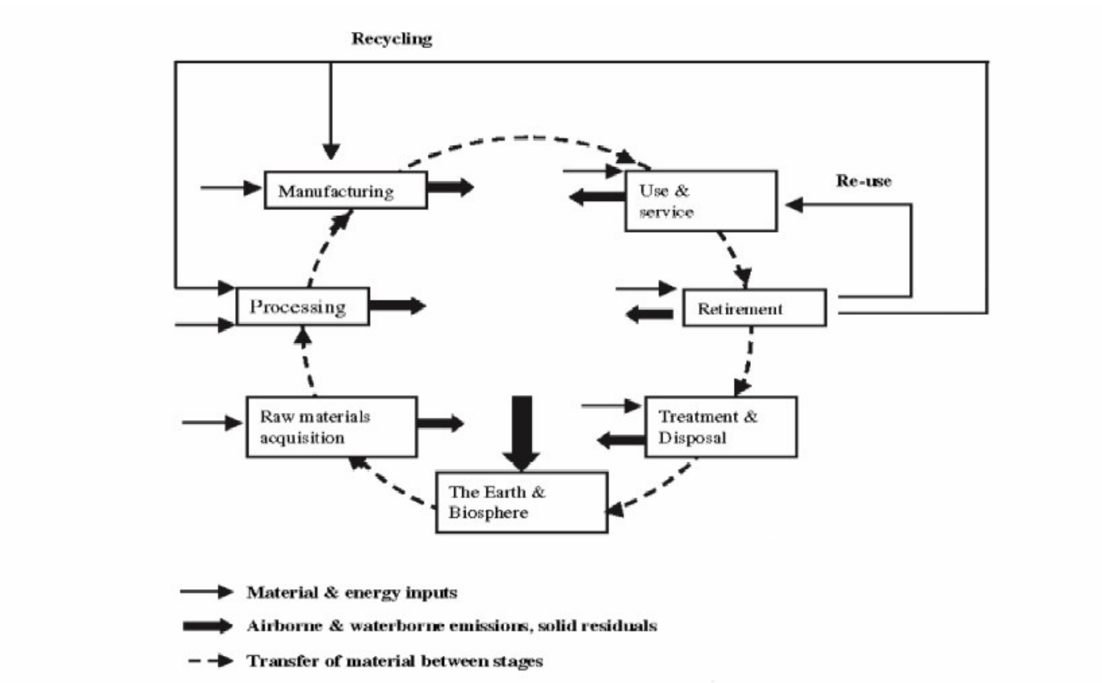

Figure 1-1-2 : Example of a Life Cycle for a Product or Commodity used by Industry (Norgate et al. 2007)

Introduction to Life Cycle Assessment

LCA is a methodology for assessing the environmental performance of a service, process, or product, including a building, over its entire life cycle. It is not possible to go into the details of LCA here, but the basic methodology for the various steps is useful to present. Life cycle assessment typically comprises four stages; (1) the goal definition and scoping stage; (2) the life cycle inventory stage, (3) the life cycle impact assessment stage, and (4) the interpretation or improvement stage (ISO 14040 2006). Life cycle impact assessment can also be re-framed as life cycle 'costing', using a variety of techniques to place a monetary value on the socio-economic and environmental impacts of alternative decisions (Krozer 2008).

Life cycle assessment tools assess impacts on a variety of environmental values, including air and water quality, greenhouse emissions and land use for a suite of activities undertaken during construction. 'Cradle-to-gate' LCA assesses alternative construction activities from design to built and in use forms, whilst 'cradle-to-grave' LCA assesses the commodity throughout its life-cycle, both during and after direct responsibility of the producer.

The goal and scope stage outlines the context of the LCA, whether it will be construction-only, cradle-to-gate, cradle-to-grave or cradle-to-cradle. The inventory also determines what data is available, and which operations and environmental parameters will be included. A risk-based assessment should be used to determine which operations in the construction process should be assessed, and which environmental parameters / impacts within each operation should be quantified.

The inventory analysis provides detailed material and energy balances over the system as identified in the goal and scope definition. All quantities of material and energy inputs, and product and emission outputs to air, water, and land are compiled into one inventory.

Following the inventory, the life cycle impact assessment phase typically has three components (ISO14040 2006): Classification: where the results of the inventory are categorised into impact categories; Characterisation: where the contribution of inventory data to each impact category is determined; and Valuation: whereby the different impacts are normalised and weighted against each other (Mangena and Brent 2006). The valuation step is optional in an LCA. If this step is undertaken the previous results need to shown in order to provide the necessary transparency. Environmental impacts to be quantified are selected and defined in the goal and scope definition. The choice of Environmental impacts may differ for different LCA studies. Within one LCA study the same environmental impacts need to be considered in each stage of construction

A major concern with LCA, like any impact assessment process (including GreenStar NZ), is the way that values are attributed for different types of impacts. The valuation step is optional – characterised results need to be shown as well. This means that the user of the results can decide whether one considers climate change more important or ozone depletion. Regardless, once values are quantified, LCA can be a useful decision support tool for comparing project or process options within an agreed values framework.

The science behind LCA is still developing. Since life cycle costs cannot be unambiguously attributed, especially in multi-product process chains (Johns et al. 2008), LCA should only be used as a decision support framework, rather than a complete decision making tool.

1.1.3 MWH Commission

MWH NZ were engaged to prepare a peer review of Greenstar self-assessment of a building design constructed from four different materials; concrete, steel, timber and timber plus. The preliminary work involved comparing the self-assessments (concrete, steel, timber) provided by Scion under the base scenario with the GreenStar Office Design V1 building rating tool. Scion also provided two context documents detailing the research approach and the operational energy details of the base building. The brief was to provide Scion with a peer review as to whether the assumptions they had made and comparisons drawn between GreenStar Office Design V1 and LCA were appropriate for the limited credits selected for the purposes of this study. The credits selected by Scion for the purposes of this study included; ENE1, ENE2 and MAT 1-12.

Results of the peer review were supplied to Scion by MWH to enable their final reporting. The peer review of the results summarised below details results of the initial GreenStar Office Design V1 self-assessments submitted to MWH from Scion under the base scenario and LCA results also submitted by Scion. MWH have reviewed the documentation in conjunction with current industry practice and their knowledge of the GreenStar system gained whilst helping the New Zealand Green Building Council to develop the first GreenStar buildings rating tool for New Zealand. MWH also keep current with GreenStar NZ technical updates by delivering professional development training for GreenStar professionals on behalf of the New Zealand Green Building Council and whilst acting as technical advisors to the New Zealand Green Building Council technical advisory working group. This peer review has been undertaken using MWH current knowledge in the constantly evolving field of environmentally sustainable design and our own industry experience in designing green buildings.

1.2 Peer Review of LCA and GreenStar NZ Office V1 Results

The aim of this section is to compare the results of the Scion life cycle assessment and the GreenStar NZ Office Design V1 tool self-assessments carried out by Scion, based on the same assumptions. The relevance of the research approach (basic assumptions) and interpretation of results will be discussed in the conclusions.

The number of points awarded (for two categories materials (whole category) and energy (ENE1 and ENE2)) as well as the weighted total score (based on these categories) for the steel, concrete, timber and timber plus building are shown in Table 1-2-1.

Table 1-2-1: Green Star NZ Office Design V1 results – Base scenario

	Credits	Weighted score
Timber building	5	5
Timber plus building	5	5
Steel building	5	5
Concrete building	6	6

The GreenStar NZ Office Design V1 ranking of the buildings based on self-assessments;

1. Concrete
2. Steel/Timber/Timber plus

In comparison the LCA results have shown the following ranking for primary energy use as well as GWP in the base scenario:

1. Timber plus
2. Concrete
3. Timber
4. Steel

Under the base scenario the GreenStar NZ assessments rated the use of concrete most favourably in construction but did not separate steel, timber and timber plus. Whereas LCA demonstrated clear differences in the desirability of the different materials from an energy use and global warming potential perspective, with timber plus having the least sensitive environmental profile.

Table 1-2-2: Green Star NZ Offie Design V1 results – Recycling scenario

	Credits	Weighted score
Timber building	8	7
Timber plus building	8	7
Steel building	10	8
Concrete building	8	7

The GreenStar NZ Office Design V1 ranking of the buildings based on the results would be;

1. Steel
2. Concrete/Timber/Timber plus

In comparison the LCA results have shown the following ranking for primary energy use as well as GWP in the reutilisation scenario:

1. Timber plus
2. Concrete
3. Timber
4. Steel

Under the re-utilisation scenario GreenStar NZ was unable to differentiate between concrete, timber and timber+ and rated steel as the optimal building material. Using energy use and global warming potential data LCA assessment of the same information showed timber+ as the least environmentally degrading.

1.3 Discussion and Conclusions

When examining the credits awarded in the self assessments carried out by Scion as described above for the different building materials it became evident that individual credits in this particular case are largely irrelevant. It is more appropriate to measure the percentage contribution of the credits to the final score, taking into account not applicable credits and category weightings. For example: 6 credits of a possible 24 credits multiplied by the category weighting gives a 2.5% contribution to the final score, but 6 credits of a possible 21 credits multiplied by the same weighting gives a 2.86% contribution to the final score. The percentage contribution to the overall category score of specific credits allows a more accurate assessment of the relative importance assigned to the selected credits under the GreenStar NZ system and a more meaningful comparison with LCA.

The GreenStar NZ Office Design V1 tool proved to be of limited consistency with respect to comparisons with life cycle assessment as the basic assumptions of the study did not align with those of GreenStar NZ. Under the GreenStar NZ Rating systerm a building will inherently perform well in certain areas and not in others, but good design practice will be rewarded by a balanced scorecard approach for the overall building rating. The assumption in this study of consistent performance of the base building in those credits not under comparison does not align with the premise of GreenStar NZ. It is highly unlikely that any base building made from such diverse materials as have been compared in this study would not demonstrate differences in other credits beyond materials and energy. This is an academic exercise however and has been reviewed as such.

The study revealed that the level of refinement of the GreenStar NZ tool was not able to determine a difference between the timber and the timber plus building, both share the same results in the Green Star NZ assessment. This result could be attributed to a lack of volumetric accounting of material proposed for construction; the GreenStar NZ-based rating tool used material costs as a percentage of the total contract costs. However. in pragmatic terms this was not a significant issue for this study because the building design assumptions proved to be unrealistic, whereby constructing a building of the design proposed, in wood alone (timber or timber plus) would not be compliant with building code. The GreenStar NZ tool lacked sufficient refinement to discern the order of desirability of the less preferable construction materials and function as a design rating tool that could also support sound decision making at the planning stage.

The approach adopted for this research study was consistent and allowed comparison to be drawn between the tools, however the lack of availability of detailed data on the cost contribution of specific materials was limiting as some of the GreenStar NZ materials credits depend upon this information in order to award points. The material contract cost attributes required under GreenStar NZ and the material cost cut off rules for steel and concrete (1 % of project contract value) and timber (0.1 % of project contract value) were incepted to reflect the "average" building and based upon estimations from certified quantity surveyors. The cut off points were designed to allow points to be awarded only where a measurable proportion of the total contract cost was accounted for in material that had been recycled. GreenStar NZ aims to drive good practice and take a balanced scorecard approach in buildings where recycled materials cannot be fully utilised. The credits for recycled concrete, steel and FSC certified timber are awarded for buildings unless they fail to meet the cut off criteria and then the "Not Applicable" option applies. When credits are not applicable under one credit criteria, the other points in that category become more valuable as the unclaimed credits are spread evenly across the other applicable credits.

Using the base and recycling scenarios highlighted the changes possible in building rating by simply selecting different core materials versus the impact of full recycling on the overall GreenStar NZ building rating. There were changes in the most preferred material type but a lack of differentiation in the other possible materials for both scenarios. In order for the scenarios to differentiate more clearly under GreenStar NZ it would be essential to have more quantifiable data around re-use as a percentage of total contract value and some detail on the fit-out. The reviewers are aware that fit-out was beyond the scope of the study, however it is a strong component of GreenStar NZ and some assumptions could have been made based on the current building.

Of central importance to the design of the study covered by this report was the requirement to have all four alternative designs displaying very similar operational energy consumption over the lifetime of the buildings. Previous research has shown that even when the energy efficiency of buildings being compared is code-compliant, the effects of the embodied energy of construction materials are difficult to differentiate in comparison to the much larger variations in operational energy between the different buildings (Wayne and Trusty, 2007). Choosing similar operational energy consumption of the four buildings being compared in this report means that the differences in the environmental impacts are determined by the differences in the embodied and recurrent (maintenance and refurbishment) energy and GWP emissions in the different materials used in each building. To achieve very similar operational energy profiles required different design for envelope walls construction, thermal mass, and heating and cooling equipment in each of the four buildings. This fundamental variation was not able to be reflected in the GreenStar NZ self-assessments under the limited credits chosen and resulted in skewed reporting of the ratings achieved.

The energy category (25%) is given a higher weighting than the materials category (10%) for influencing the overall score of the Green Star rating and this was consistent with the LCA assessment which showed that the operational energy use dominates the results over the whole life cycle.

All four buildings in this research had similar performance profiles (close to 85 kWh/m^2/year). This was important because the aim of this study was to look at the influence of materials on the life cycle energy use and GWP emissions of the buildings. Natural gas was used as fuel for the heating system and domestic hot water. Electricity is used for cooling, lighting and office equipment energy. The energy mix was important when considering GWP since two buildings having the same total energy might use different proportions of gas and electricity. Not all energy is equal; combustion emissions differ by energy form and the upstream, pre-combustion implications of producing and moving different energy forms can be even more significant. Thus buildings with the same total operational energy use may not result in the same GWP emissions, for example, LPG has a much higher carbon dioxide coefficient than electricity. Indeed the carbon dioxide rating of electricity varies significantly depending on how the electricity is generated and where (which country) it is produced. A rating system promoting minimal energy use without regard for the form may be misleading, especially if it results in the use of materials or construction techniques that have significant resource use or emission implications in their own right. The energy mix is of vital importance for the GreenStar NZ rating system and different mixes would have been awarded different credits under the criteria of the energy calculator, hence the consistent approach used in this study was appropriate for the desired outcomes.

The base building was not an office building, it was based upon the laboratory buildings for the Biological Science facilities at Canterbury University, therefore the use of the Office Design tool was of questionable value. However, in the absence of any other more appropriate tools (*i.e.* the GreenStar NZ Education tool currently under development) the study carried out has highlighted some areas in need of further work, these areas are covered in the following section of the report. Arguably using the Office Design V1 tool would have skewed the rating results as the weightings have been derived to reward best practice in designing office buildings rather than education establishments. The principles of GreenStar NZ remain the same across tools, but how they are applied varies according to specific applications, this study provides a positive starting point for discussion.

There were relatively small differences between the results from base and re-utilisation scenarios. This was in part due to the limited number of credits chosen for comparison. The assumptions of no differences in inherent building characteristics for those credits not under scrutiny for each material assessed did not align with the basic premise of the GreenStar NZ rating tool which caters for fundamental differences in buildings using offsetting of credits in other categories to drive positive changes in behaviour.

The wide use of not applicable for the self-assessments where circumstances are considered the same for all four buildings or where data does not exist may have biased the results from GreenStar NZ as credits that are deemed not applicable in one credit are equally spread across the remaining credits in the category. This re-distribution of points results in a change in the overall importance of the remaining credits in the catgeory.

There are substantial rewards under the material category of the GreenStar NZ for recycled content of steel and concrete and integrated fit out. These drivers do not account for the environmental benefits demonstrated by LCA from the use of post-consumer timber, resulting in the GreenStar assessment considering the concrete building option to be optimal. The presumption of GreenStar NZ and most green building rating systems is that recycled materials will automatically result in reduced environmental burdens. However, this may not always be the case and recycling in any given situation may be a positive or negative attribute. For example recycling can save landfill space, but the process of recycling of any given product may take more energy and adversely affect air quality more than production from raw materials. The focus on recycling can ignore the possibility and give more weight to solid waste and resource depletion issues than global warming or other measures. One issue or indicator does not take precedence over the other, but commonly held assumptions can drive the shape of rating tools over data and facts when decisions are made during tool planning. It may be prudent to re-visit the objective of recycling during the review phase of the GreenStar NZ tool to align the ratings to the initial aim to reduce the flows from and to nature.

There were found to be aspects of the GreenStar NZ tool that were constrained when trying to fully integrate LCA-based tools into this building rating system. Two, in particular deserve emphasis; the problem of data availability, and the absence of appropriate references or benchmarks against which to judge LCA results for a particular building.

GreenStar NZ is clear in its aims and in some cases is driving better practice; The energy credits aim to reduce greenhouse emissions from operation of the building (carbon dioxide emissions), to use energy more efficiently and reduce peak loads. The reality is that energy rating is heavily dependent upon building fabric, building services systems and expected electrical and mechanical loadings. In the majority of modern buildings there is a fine balance between natural light and thermal gain. The Façade is also an important factor in determining the final energy rating. This supports the notion that a more holistic measure is required to capture all these linked aspects of the energy equation. The material credits aim to minimise resource consumption through material selection, use and re-use initiatives, support third party life cycle assessment programs and efficient management practices. There are gaps in the data currently available to populate third party verification schemes such as Environmental Choice due to the lack of independently verified specifications available through accredited suppliers. This is an active area of research and as data becomes available it will inform the GreenStar tools. Recycled steel and concrete at this stage are not practical due to a lack of information available from suppliers and indeed a lack of choice of products. In addition, as previously discussed, recycling may not always prove to be the best environmental choice.
The integrated interior fit-out strategy is important and does drive efficiency in management. A major limitation in the material category is the lack of environmental choice products for developers to choose from and be confident that they are making a sound decision.

In order to encourage the uptake of LCA and incorporate all estimated effects and not proxy measures it will be necessary to educate the public as to why informed environmental choice is important. It will be important to emphasise the need for assessing whole buildings and the inherent relationships in a building system where the choice of one material for an application may dictate the use of other materials for thermal or other reasons.

1.4 Further Work

The difficulty in maintaining complete objectivity in building assessment systems is most noteable in the material selection criteria and to a lesser extent in the energy use criteria. Defining sustainable materials presents a confounding challenge for Scientists. Ultimately a better integration of LCA techniques and LCA-based decision support tools in whole building rating and certification systems is preferable.

Based on this study there are several options for further work that would add to the growing body of knowledge in this vital research area, some of these are detailed below. During the review phase of the GreenStar NZ tools provide feedback to the New Zealand Green Building Council around alignment of the ratings to the initial objective to reduce the flows from and to nature. Data to support this important feedback would be essential to ensure changes could be incorporated into future tools.

Once the GreenStar NZ Education tool has been released it may be prudent to re-run the self-assessments and compare LCA with the appropriate application-specific green building rating tool.

A further study comparing results obtained for similar self-assessments with BREEAM and LEED as alternate green building rating tools that have had the opportunity to mature in the market.

Further work around true life cycle costs for beneficial re-use options for recycled materials and investigating barriers to LCA data availability for New Zealand is suggested.

Provision of research data to companies trying to become Environmental Choice certified would enable the market to have better data across a wider range of products and this would encourage their wider use.

A more comprehensive treatment of other credits where LCA would be invaluable is recommended, examples include; MAN-7 (quantifying the impact of waste diverted from landfill) or EMI-5 (assessing the life cycle costs of reducing flows to municipal sewage systems).

The issue of data availability across borders to ensure comparability and the obvious commercial sensitivity of the data is an outstanding issue requiring resolution at a high level. Raising the profile of LCA as a decision support tool at government level would be fundamental to winning further funding to develop New Zealand-based data. When judging the significance of data with respect to references or benchmarks the ultimate answer lies in developing case studies of different types of conventional buildings in different regions that can serve as benchmarks. There are compelling reasons to have this data in terms of future proofing key decisions around climate change and adaptation.

In the long run the integration of LCA tools into whole building assessment systems will yield significant benefits, not only will it improve understanding and reward for environmental performance, but once established future LCA will be less complex and expensive. A paradigm shift is required away from conventional wisdom and related procurement decisions toward minimisation of life cycle flows to and from nature.

1.5 References

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