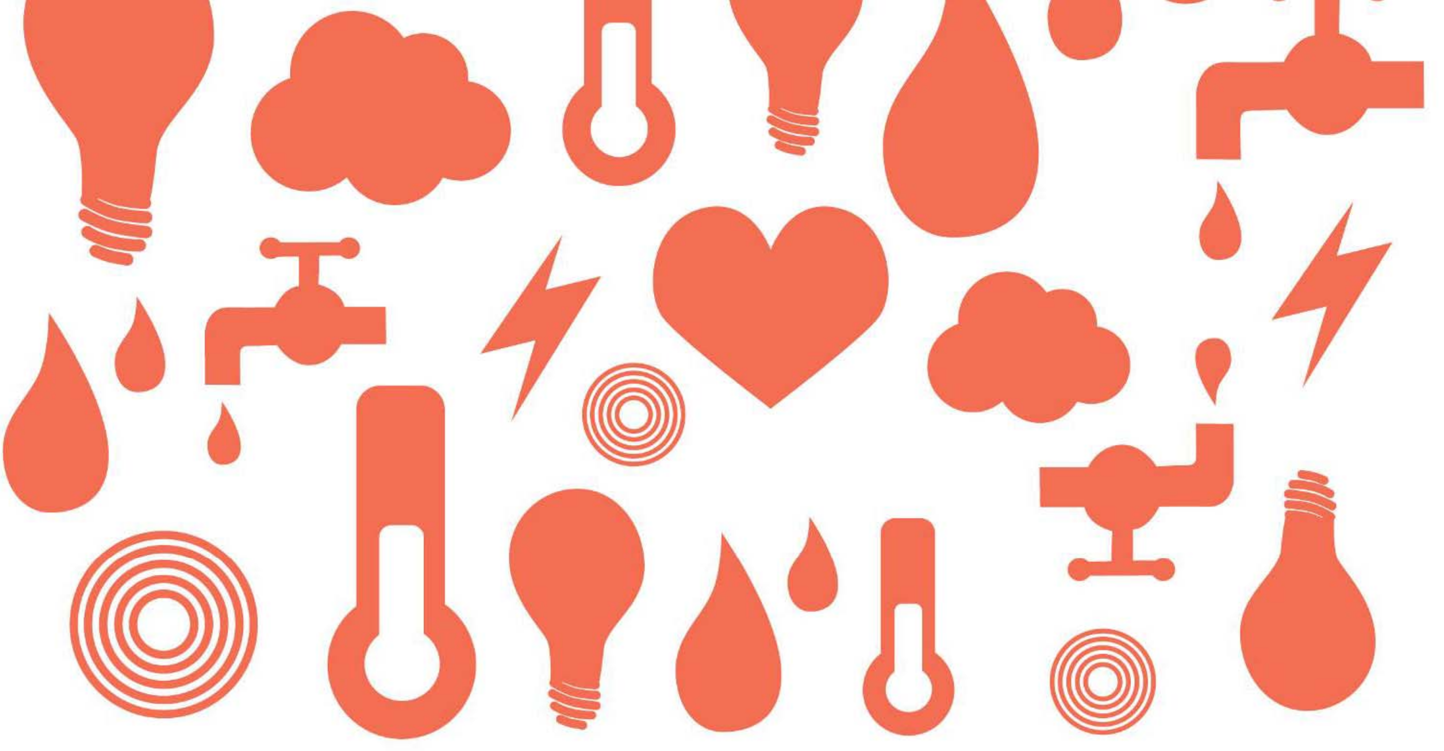

SM3570/9

# The environmental impact of the Waitakere NOW Home®: A Life Cycle Assessment case study

A report prepared for Beacon Pathway Limited

February 2010

Beacon

Creating homes and neighbourhoods that work
well into the future and don't cost the Earth

## About This Report

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**ABSTRACT**

A Life Cycle Assessment case study of Beacon Pathway's Waitakere NOW Home® indicates that the greatest environmental impact of a house is not during construction or manufacturing, but from its operation over the life of the house. The study focused on the house itself over a 100-year period in New Zealand, with a family of four inhabiting it. Heating, lighting and hot water were considered, and seven key building systems were evaluated separately. Life cycle phases of construction, use, maintenance, transportation of materials to site and end of life were included. New Zealand-specific Life Cycle Inventory data was used, wherever possible, for building materials. However, where New Zealand data was unavailable, European industry data was used.

**REFERENCE**

Collins, N. and Blackmore, A. February 2010. *The environmental impact of the Waitakere NOW Home®: A Life Cycle Assessment case study*.Publication SM3570/9 for Beacon Pathway Limited.

Original report: Drysdale, D. and Nebel, B. August 2009. *Life Cycle Assessment of the Waitakere NOW Home®*. Report SM3570/8 for Beacon Pathway Limited. Available from www.beaconpathway.co.nz

# Executive Summary

Over recent years, debate has raged over which are the most environmentally friendly materials to use in construction. The discussion has focused on the environmental impact of the material itself, frequently calculated using Life Cycle Assessment (LCA). However, this case study of Beacon Pathway's Waitakere NOW Home® indicates that the greatest environmental impact of a house is not during construction or manufacturing, but from its operation over the life of the house.

### *Parameters*

LCA analysis of the Waitakere NOW Home® included the life cycle phases of construction, use, maintenance, transportation of materials to site and end of life. However, it did not include installation and deconstruction of the house. The study focused on the house itself over a 100-year period in New Zealand, with a family of four inhabiting it. Heating, lighting and hot water were considered, and seven key building systems were evaluated separately: Floor / foundations; External walls; Internal walls; Ceiling / roof; Windows; Doors; Integrated water systems.

The Waitakere NOW Home® design was tested against four alternative designs.

- Alternative design 1 replaced the concrete floor with a suspended timber floor.
- Alternative design 2 replaced the timber weatherboard external walls with brick cladding.
- Alternative design 3 replaced the concrete tiles with steel roofing.
- Alternative design 4, all three systems above, in combination, were replaced

The environmental impacts studied in the Waitakere NOW Home® LCA were:

- Global warming potential 100 Years
- Acidification potential
- Eutrophication potential
- Photochemical ozone creation potential
- Energy consumption

New Zealand-specific Life Cycle Inventory data was used, wherever possible, for building materials. However, where New Zealand data was unavailable, European industry data was used.

### *Using the house has the greatest environmental impact*

The operational stage of the Waitakere NOW Home® had by far the greatest environmental impact of any of the life stages. The operation contributed around 65-76% of each of these categories: acidification potential, global warming potential and energy consumption of the building. In fact, combining the operational and maintenance stages, as would more realistically reflect the period of use of the house, accounts for the vast majority of impacts in these categories (85% of acidification potential; 86.2% in global warming potential; and 89.1% of energy consumption).

The construction and maintenance stages were the next biggest contributors to the life cycle impact. Each had similar contributions, except for photochemical ozone creation potential. Regular repainting meant the maintenance stage had a greater impact (61%) – paint has a high photochemical ozone creation potential per litre.

The construction stage had a low global warming potential because of the net negative global warming potential of the built-in timber. The global warming potential of all the building systems that contained timber was lowered due to the storage of $CO_2$. The end of life stage had the smallest contribution to the life cycle impact.

### *The original Waitakere NOW Home® design got it right!*

When the Waitakere NOW Home® was compared to four alternative designs, the original design had the lowest life cycle impact for energy consumption and global warming potential. The original design had the lowest operational impacts because the energy storing capacity of the concrete slab reduced space heating to a minimum.

The brick cladding alternative had the lowest life cycle impact for acidification, eutrophication and photochemical ozone creation potential because the brick cladding did not require repainting, which reduced the construction and maintenance impacts.

The suspended timber floor alternative design had a higher maintenance impact due to re-carpeting. It also had the highest operational impact, but the lowest construction impact for global warming potential because of the stored $CO_2$ within the timber.

All the designs had the lowest life cycle impact in Auckland largely because of the lower heating demand during use. Increases in operational impact between Auckland and Wellington ranged from 120% for the suspended timber floor design to 183% for the original Waitakere NOW Home®.

### *Conclusions*

The Waitakere NOW Home® case study clearly shows that our biggest opportunity to reduce the environmental impacts of our homes is to improve their performance and operation. It is less significant which construction material is chosen than which combinations of products minimise the environmental impacts during the operational life of the building. When the whole life of a building is considered, and given the length of the operation phase compared to other phases, the manufacturing impact of a particular product may be relatively small.

Efforts should focus on how to get the best results during operation, in particular, by reducing the energy requirements for heating and hot water supply through good solar orientation and passive solar design.

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# 1 Introduction

## *1.1 Taking a systems view of houses*

Beacon Pathway's research is focused on creating sustainable homes and neighbourhoods by changing the way the residential built environment in New Zealand is designed, built and modified. Beacon's vision is:

**Creating homes and neighbourhoods that work well into the future and don't cost the Earth**

Beacon's thinking has always regarded the home as a system. This is embedded in our 'whole of house' approach to new homes and renovation, which is based on the principle that specific building materials and technologies are part of the whole house and cannot be seen in isolation. Beacon believes that we need to focus on the whole of the house in order to really get a fundamental change in our homes and their effect on the natural environment and on our quality of life. Our houses are a web of interdependent features and building systems. Often fixing one aspect results in compromise and under-performance in others: the challenge is to optimise all aspects in relation to each other.

Beacon's HSS High Standard of Sustainability® provides a definition for high performance in New Zealand homes. Taking a holistic view of the house, the HSS® sets benchmarks in energy water, indoor environment quality, waste and materials, underpinned by principles of affordability and flexibility. Intensive monitoring of occupied homes in Beacon's live NOW Home and Papakowhai research projects has underpinned the development of the HSS® benchmarks. These benchmarks have provided a tool against which to measure outcomes for Beacon (just how much does a home need to be renovated to reach the HSS®?), and have contributed to the star performance rating systems of the residential rating tool.

## *1.2 Beacon's systems approach*

In 2007 Beacon adopted a systems strategy which laid out our understanding of 'systems' and specified a stream of research designed to help our understanding of how better systems could improve the performance of New Zealand homes.

This reflects Beacon's belief that the combination of systems that go into a house directly affects the home's overall performance during all parts of its lifecycle. Treating the house as a system means the impact of materials can be evaluated in terms of the performance of the systems they are part of. Overseas experience has demonstrated that energy consumption can be reduced by 40% or more through the use of a systems engineering approach[1].

The strategy defined a system as the smallest part of a building with one or more shared functions (e.g., static properties, sound transfer or insulation). By defining a system by function, different design options with different environmental outcomes can be described and compared in order to provide greater functionality to homes.

Building on the areas identified in the HSS High Standard of Sustainability® as having significant environmental impact – energy, water, indoor environment quality, waste and materials – the systems research focused on finding the systems which can best meet the benchmarks set in the HSS®.

One way of analysing and evaluating the sustainability and environmental performance of buildings and their systems is by using Life Cycle Assessment (LCA).

### Life Cycle Assessment

Life Cycle Assessment is a technique for systematically evaluating the environmental impacts of a product or service though all the 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.

The research took a novel approach of applying LCA methods to a home. Life Cycle Assessment and Life Cycle Inventories were undertaken on the Waitakere NOW Home® and on two of the Papakowhai Renovation homes. These research homes provided useful case studies as their performance was intensely monitored and accurate materials data on new-build and renovation were available.

As a supplement to the Life Cycle Assessment on the five research homes, a second report focused on applying available New Zealand data to the Waitakere NOW Home® as a single case study (summarised here). Results from the Waitakere NOW Home® LCA match closely with results from the other houses.

[1] *US Department of Energy. Building America program. http://www1.eere.energy.gov/buildings/building_america/systems_engineering.html*

# 2 The Waitakere NOW Home® case study

## What is the Waitakere NOW Home®?

The Waitakere NOW Home® was Beacon's first live research project, designed and built to show that a sustainable house could be built **now** using materials and products available today. By using simple, proven designs and technologies in combination, the Waitakere NOW Home® addressed the sustainability of the **whole** house including energy efficiency, water, indoor environment, waste and material selection.

The home was extensively monitored, over a two year period, while tenanted by a young family. Data was collected on energy use, water use, rainwater collection, temperature, indoor air quality, and humidity and moisture levels.  It has provided sound scientific proof of the benefits of living in a sustainable home. Social research captured the story of the tenants' experience and has shown a wide range of social, health and emotional benefits beyond the immediate financial and resource savings

## Features of the Waitakere NOW Home®:

- a single storey, three bedroom home of 146 $m^2$ (including the garage)
- built at a cost of $218,000 + GST, equal to average house costs at the time
- designed to reduce water, energy and resource use
- designed to provide a comfortable, attractive and healthy living environment
- built from materials and with practices that are as good as, or better than, Building Code minimums
- used best practice and best use of today's materials and technologies in creating a building to meet the needs of the future
- built from materials chosen for integrity and durability to maintain capital value and ensure weathertightness
- used, where possible, materials made from renewable sources and chosen for low toxicity

# 2.1 Setting up the Waitakere NOW Home® LCA

### *2.1.1 Goals and objectives*

The goals of this LCA study were to:

- identify the environmental hot spots of the Waitakere NOW Home® in order to further identify the systems that contribute the most to the environmental impacts of a home;
- compare the embodied energy in the construction of the Waitakere NOW Home® with the operational energy use during the use phase; and
- compare the life cycle impact of the actual NOW Home® design with four alternative NOW Home® designs in two other climate zones.

### *2.1.2 Scope of the case study*

The analysis took into account the life cycle phases of construction, use, maintenance, transportation of materials to site and end of life.

- *Construction* accounts for the embodied impacts of the materials within the building, along with the transport of those materials to the building site.
- *Operation* accounts for the total primary energy consumption of the Waitakere NOW Home® for heating, lighting and hot water end-uses, during its 100 or 50-year lifetime.
- *Maintenance* accounts for the embodied impacts of the materials required to maintain the building throughout its lifetime, along with the transport of maintenance materials to the house.
- *End of life* accounts for the transportation to and processing of all the building materials in landfill, which includes the original building materials as well as maintenance materials.

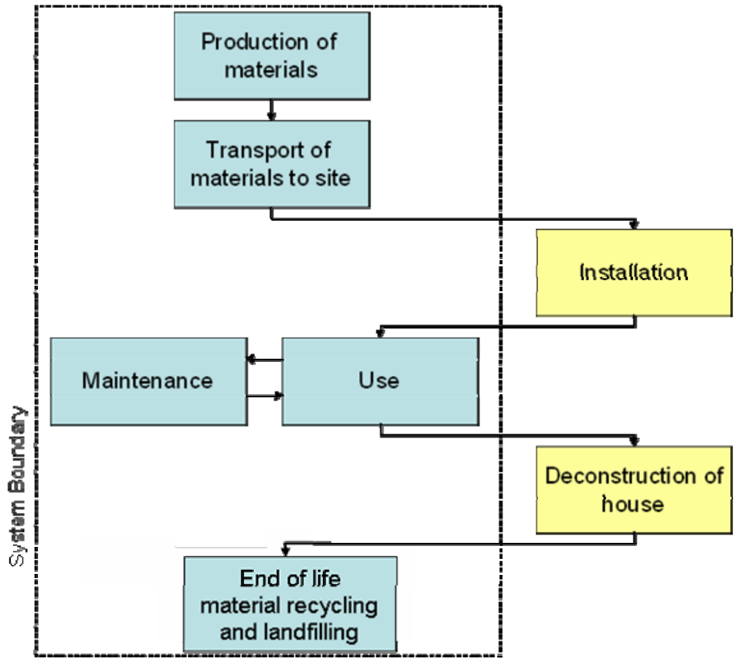


*Figure 1: LCA system boundary for the Waitakere NOW Home®*

### 2.1.3 The system boundary

Setting the system boundary determines where a life cycle begins and ends and defines what processes to include in the study[2]. For the Waitakere NOW Home® case study the boundaries of what systems were included, are shown in Figure 1.

For this project, the systems boundaries excluded the installation of products / services during construction, and the final deconstruction of the house[3]. The provision of infrastructure and capital goods, such as roads, trucks for transport, machinery etc., was not considered as the impacts were estimated to be negligible[4].

This study assessed the embodied impacts of the materials within the structural systems of the building, i.e. building envelope and internal walls. The embodied impacts of building systems that provided a service such as electricity, lighting, extractor fans, solar hot water system etc., have been excluded from the system boundaries. This is because the decision to select these service systems is not governed by the materials that compose them but by the desire for the system and its benefits. In other words, installing these systems is less subject to material choices. However, the energy savings from installing these devices were considered as part of the study.

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*[2] For more information on system boundaries, see Appendix One: What is Life Cycle Assessment?*
*[3] The impacts of installation/construction and deconstruction are considered to make only a minimal contribution to the overall life cycle impact (Kellenberger and Althaus, 2008).*
*[4] Frischknecht et al., (2007)*

### *2.1.4 Functional Unit*

The functional unit defines the product or service for which data is being collected. Rather than looking at a certain mass of material, it looks at the function or the service which is provided by a certain product. By stating the functional unit upfront, the material flows (input and output data) of an LCA can be compared to LCA data for other products.

Unusually, this case study has set the functional unit as the Waitakere NOW Home® itself. It considers the house over a 100-year/50-year period in New Zealand, as a home for a family of four. Energy used for heating, lighting and hot water was included. All results are presented in terms of this functional unit.

### *2.1.5 Building systems*

The case study also considered the environmental impact of different building systems within the functional unit. The seven main systems analysed in this study are:

- Floor / foundations
- External walls
- Internal walls
- Ceiling
- Roof
- Windows
- Doors
- Integrated water systems and other components

### 2.1.6 Areas of environmental impact

The systems approach is applied to the impact assessment of an LCA as well, by taking a number of different environmental impacts into account[5]. The key environmental issues assessed in this study are the following:

- Global warming potential
- Acidification potential
- Eutrophication potential
- Photochemical ozone creation potential
- Energy consumption

The environmental impact categories were chosen on basis of available data and established methodologies. Four toxicity categories (namely human toxicity (HTP), marine aquatic ecotoxicity, freshwater aquatic ecotoxicity and terrestrial ecotoxicity) were not studied as their complexity means that accurate methodologies are still under development and were considered uncertain in comparison to the impact categories chosen. Ozone depletion was considered redundant now that it is prohibited to produce products which release ozone depleting emissions during use or in production. Methods for water consumption as an impact category are in their infancy in LCA in New Zealand and were considered still highly debatable.

### 2.1.7 Sources of data

Where possible, New Zealand specific life cycle inventory data[6] was used for building materials.

When New Zealand specific data was currently unavailable, the life cycle inventory data for those building materials was based on European industry data[7]. The data was amended and checked for consistency with literature data and is compliant with the ISO Standards 14040 and 14044. The data covers resource extraction, transport, and processing i.e. "cradle to gate". Included are material inputs, energy inputs, transport, and outputs, as well as the emissions related to energy use and production. The use of European data for some building materials (adapted to reflect New Zealand energy, local materials and transport) is a limitation of this study. However, the results still provide indicative results that allow a meaningful hot spot analysis.

A dataset for the New Zealand specific electricity GridMix is provided in the GaBi database. This dataset is based on the average GridMix of New Zealand in 2004. The impact from generating 1 MJ of electricity for each electricity generation system (e.g. coal, hydropower, natural gas) is based on European data.

Life cycle inventory data was unavailable for timber treatment chemicals in the Gabi database; therefore the life cycle impact of the treatment chemicals was excluded from this assessment.

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*[5] For more information on the selection of environmental impact categories, see Section 3 Discussion*

*[6] Nebel et al. (2009)*

*[7] GaBi database 2006*

### *2.1.8 Alternate Waitakere NOW Home designs*

Three alternative building systems within the NOW Home® were assessed in this study, replacing the original respective systems (above). The replacement of each original system constitutes a new NOW Home® design and only one system is replaced at a time, plus a fourth which involves replacing all three systems, in combination, in the NOW Home®.

The systems included in the Waitakere NOW Home® and each alternative design are listed below along with the components within each system

| Waitakere NOW Home® | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Floor/foundations** | | | | |
| - Hardfill<br>- Concrete slab and footings (includes timber boxing)<br>- Concrete slab insulation<br>- Flooring materials (includes hydrocoat epoxy sealer, carpet and ceramic tiles) | - Hardfill (under garage concrete slab only)<br>- Suspended timber floor (including all the relevant timber components, e.g. piles, joists etc.) and garage concrete slab (includes timber boxing)<br>- Underfloor insulation<br>- Flooring materials (includes vinyl, carpet and tiles) | Same as Waitakere NOW Home | Same as Waitakere NOW Home | - Hardfill (under garage concrete slab only)<br>- Suspended timber floor (including all the relevant timber components, e.g. piles, joists etc.) and garage concrete slab (includes timber boxing)<br>- Underfloor insulation<br>- Flooring materials (includes vinyl, carpet and tiles) |

| Waitakere NOW Home® | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **External walls (part of building envelope)** | | | | |
| - Exterior finish (i.e. timber weatherboard cladding, paint etc.)<br>- Framing<br>- Interior finish (i.e. internal gypsum board lining, skirting, paint etc.)<br>- Insulation | Same as Waitakere NOW Home | - Exterior finish (i.e. brick cladding etc.)<br>- Framing<br>- Interior finish (i.e. internal gypsum board lining, skirting etc.)<br>- Insulation | Same as Waitakere NOW Home | - Exterior finish (i.e. brick cladding etc.)<br>- Framing<br>- Interior finish (i.e. internal gypsum board lining, skirting etc.)<br>- Insulation |
| **Internal walls and partitions** | | | | |
| - Framing<br>- Finish (i.e. gypsum board lining, skirting, paint etc.) | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home |
| **Ceiling and roof** | | | | |
| - Ceiling (i.e. gypsum board lining, steel nail up battens, paint etc.)<br>- Insulation<br>- Framing<br>- Roofing (i.e. concrete tiles, battens etc.)<br>- Eaves (i.e. fibrecement soffits, PVC joiners etc.)<br>- Fascia guttering (assumed main function is fascia) | Same as Waitakere NOW Home | Same as Waitakere NOW Home | - Ceiling (i.e. gypsum board lining, steel nail up battens etc.)<br>- Insulation<br>- Framing<br>- Roofing (i.e. steel roofing, battens etc.)<br>- Eaves (i.e. hardisoffit, PVC joiners etc.)<br>- Fascia guttering (assumed main function is fascia) | - Ceiling (i.e. gypsum board lining, steel nail up battens etc.)<br>- Insulation<br>- Framing<br>- Roofing (i.e. steel roofing, battens etc.)<br>- Eaves (i.e. hardisoffit, PVC joiners etc.)<br>- Fascia guttering (assumed main function is fascia) |

| Waitakere NOW Home® | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|
| **Windows (includes aluminium framed glazed doors)** | | | | |
| - Aluminium framing<br>- Glass<br>- Finish (i.e. timber, paint etc. | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home |
| **Doors** | | | | |
| - Internal wooden doors<br>- Wooden front door | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home |
| **Integrated Water Systems** | | | | |
| - Polypropylene downpipes<br>- Polyethylene rainwater tank<br>- Internal plumbing | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home |
| **Other components** | | | | |
| - Garage door<br>- Pergola | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home | Same as Waitakere NOW Home |

***Table 1: Comparison of building systems in the Waitakere NOW Home and alternative designs***

## 2.2 Findings from the Waitakere NOW Home® LCA

### *2.2.1 Using the house has the greatest impact*

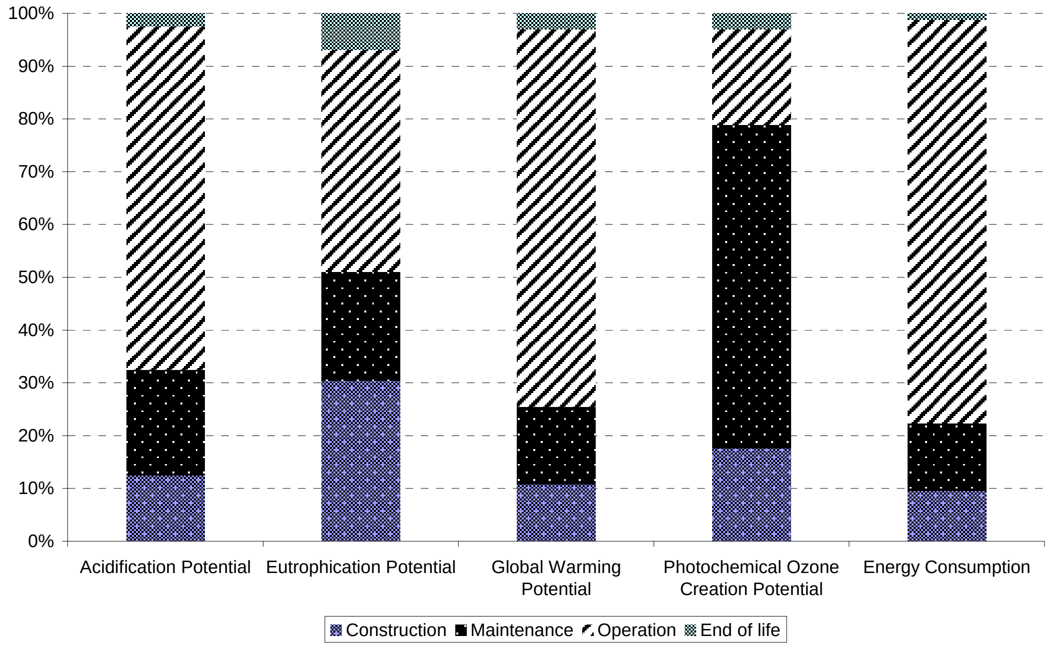


***Figure 2: Percentage contribution to environmental impacts of each life cycle stage of the Waitakere NOW Home®***

The operational stage of the Waitakere NOW Home® had by far the greatest environmental impact of any of the life stages. The operation contributed around 65-76% of each of these categories: acidification potential, global warming potential and energy consumption of the building. In fact, combining the operational and maintenance stages, as would more realistically reflect the period of use of the house, accounts for the vast majority of impacts in these categories (85% of acidification potential; 86.2% in global warming potential; and 89.1% of energy consumption).

The construction and maintenance stages were the next biggest contributors to the life cycle impact. Each had similar contributions to the overall impact, except for photochemical ozone creation potential, where the maintenance stage had the greater impact (61%) due to relatively regular repainting. Paint has a high photochemical ozone creation potential per litre.

The construction stage had a low global warming potential because of the net negative global warming potential of the built-in timber. The global warming potential of all the building systems that contained timber was lowered due to the storage of $CO_2$.

The end of life stage had the smallest contribution to the life cycle impact.

These findings are borne out by a UNEP review[8] of other LCA studies in other countries. In each case, operation was found to form the greatest impact of all categories.

[8] *UNEP (2007)*

### 2.2.2 The relative impact of each building system

Within the environmental impact of the Waitakere NOW Home® as a whole, the LCA also considered which building systems used in the initial construction of the Waitakere NOW Home® significantly contributed to its environmental impact. Within each building system, the LCA assessed which individual materials contributed most to the system's impact.

Impact is assessed based on the relative mass of each system or material, and therefore its overall contribution to the total building. However, this analysis does not take into account the environmental impacts of these building systems over the ongoing operation and maintenance of the home. As installation was excluded from the system boundary, the impacts of the actual construction work are also not included.

Figure 3 presents the contribution to each impact category of the building systems analysed in the Waitakere NOW Home®.

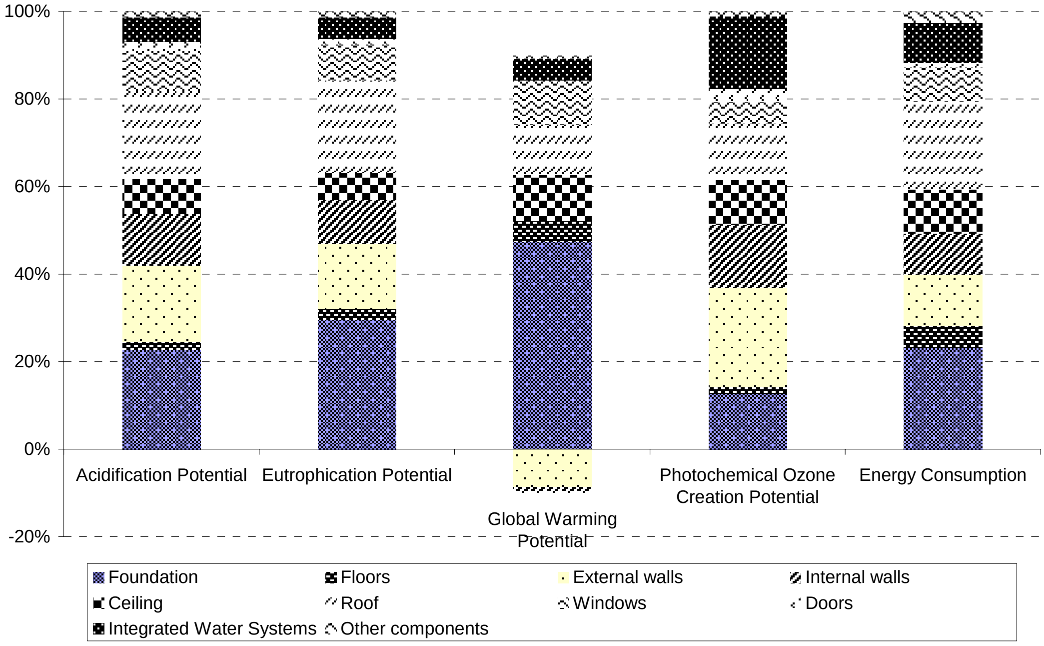


***Figure 3: Percentage contribution to environmental impacts of each building system in the Waitakere NOW Home®***

Building systems consisting largely of wood, such as the external and internal walls, had a net negative global warming potential. This reflects the permanent storage of carbon within the wood when it is landfilled.[9]

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*[9] The net $CO_2$ storage is included in the construction impact because it is an inherent property of the timber and should not be associated with the end of life stage. The net $CO_2$ is calculated from the amount of carbon that remains in the landfill permanently, once the decomposition of the timber and release of greenhouse gas emissions have ceased.*



The **foundation system** was the main contributor to each category except photochemical ozone creation potential, and dominated the global warming category, providing 53% of the impacts. The system accounted for 22% of the embodied energy of the materials used to construct the house, but also accounted for 78% of the total mass of the Waitakere NOW Home®.

Concrete was the dominant component of the foundation system, contributing from 65% (energy consumption) to 86% (eutrophication potential) to the total foundation impact. Even when considered in terms of the whole building, concrete accounted for 20% and 14% of the eutrophication potential and embodied energy impacts of the construction materials respectively. However, the concrete floor was a major contributor to the success of the passive solar design, its thermal mass properties reducing space heating needs to a handful of days each year. Given space heating typically absorbs 30% of a household's energy use, the successful use of thermal mass meant the household used 25% less energy than average 4 person households with school age children.

The **external walls** were the main contributor to the photochemical ozone creation potential impacts, and combined with the **internal walls**, the wall system dominated the category, accounting for 37% of the impact. The external wall system accounted for between 5.6% (global warming potential) to 20% (photochemical ozone creation potential) of the total construction impact, with a contribution of 4% of the mass of the Waitakere NOW Home®. The internal wall system accounted for between 8% (eutrophication potential) and 13% (photochemical ozone creation potential) of the total construction impact, and 3.8% of the mass of the Waitakere NOW Home®.

Paint finishes were a significant component of both internal and external walls. Despite accounting for only small percentages of the mass of each system (1.7% of the external walls and 1.3% of the internal walls), paint dominated the photochemical ozone creation potential contributing 56% to the external walls and 60% to the internal walls. On the scale of the entire Waitakere NOW Home® paint accounted for 20% of the total construction photochemical ozone creation potential and only 0.12% of total mass.

The **roof system** had the next largest contribution accounting for between 11% (global warming potential) to 19% (energy consumption) of the total impact from the building systems. Roofing, comprising of concrete tiles, timber battens and building paper, dominates each impact category especially energy consumption (62%).

The contribution of the **ceiling system** to the construction impact of the building ranged from 5% (eutrophication potential) to 12% (global warming potential), and accounted for 2% of the mass of the Waitakere NOW Home®.

The percentage contribution of the **windows** to the total construction impact ranged from 5% (photochemical ozone creation potential) to 11% (global warming potential), with a mass contribution of 1% of the Waitakere NOW Home®.

The **integrated water system** had a noticeably high photochemical ozone creation potential accounting for 16% of the total impact from the building systems.

### *2.2.3 The original Waitakere NOW Home design got it right!*

The study has confirmed that Waitakere NOW Home® is built from systems and materials that, when maintained, do not increase the proportion of embodied impact of the building above the proportion of the operational impact of the building. The proportion of embodied impact of the building actually decreases in relation to the proportion of operational impact over time.

No alternative designs performed better, except in particular areas. The original design had the lowest life cycle impact for energy consumption and global warming potential. The original Waitakere NOW Home® design had the lowest operational impacts because the energy storing capacity of the concrete slab reduced space heating to a minimum.

The brick cladding alternative design had the lowest life cycle impact for acidification, eutrophication and photochemical ozone creation potential because the brick cladding did not require repainting, which reduced the construction and maintenance impacts.

The suspended timber floor alternative design had a higher maintenance impact due to re-carpeting. It also had the highest operational impact, but the lowest construction impact for global warming potential because of the stored $CO_2$ within the timber.

### *2.2.4 How the designs performed in other locations*

As would be expected from the study's main findings, the operational impact dominates the life cycle impact of each building design in each climate zone. The total life cycle impact increases by around 86% (suspended timber floor) to 94% (brick cladding) from Auckland to Wellington.

All the designs had the lowest life cycle impact in Auckland largely because of the lower heating demand during use. Increases in operational impact between Auckland and Wellington ranged from 120% for the suspended timber floor design to 183% for the original Waitakere NOW Home®. However, the change in operational impact from Wellington to Christchurch is much smaller than the change from Auckland to Wellington.

# 3 What does this mean for New Zealand?

Beacon believes this case study presents New Zealand's housing industry with two exciting challenges. Firstly, new solutions and products, specifically developed to reduce the environmental impacts of the operation and maintenance of homes, are needed. And secondly, industry is challenged to ensure there is a standard, New Zealand-relevant framework for future LCA studies. Co-operation between industry, government and research community to set up such a framework and improve New Zealand's datasets will increase the usefulness of LCA data in promoting their products.

Beacon looks forward to a time when a nationally agreed approach to LCA studies and innovation solutions for improved home performance make the New Zealand building industry a world leader.

# 3.1 Seek innovative solutions to improving home operation

In studying the whole house over its life time, the Waitakere NOW Home® case study clearly shows that our biggest opportunity to reduce the environmental impacts of our homes is to reduce the impact of their operation and maintenance.

Over a 100-year lifetime, the operational phase dominates the environmental performance of the house with 65%-76% of the total impacts in acidification, global warming and energy consumption. When combined with maintenance to reflect the whole 'in-use' phase of a home's life cycle, between 86% and 89% of impacts in these categories are accounted for.

While the maintenance impact increased from 50 to 100 years, overall the embodied impact of all the materials installed in the building over its whole lifetime (construction and maintenance materials) decreased proportionally from 50 to 100 years. The longer a house is used, the more significant the operational phase and the less significant the impact of its original materials.

If the greatest environmental improvements could come from addressing the operational phase of the home, priority needs to be given to the development of innovative solutions which reduce the impact of living in and maintaining the home. Cooperation and partnership is called for to find new products and systems, or combinations of products, which will get the best results during operation to minimise impact over the life of the building. For example, finding ways to improve the thermal performance, not only of new homes, but of New Zealand's 1.6 million existing homes, will not only reduce demand for resources but provide the comfort and healthy living that homeowners need. Equally, the impact of climate change means that finding water management and space conditioning solutions will be vital to adapt to change.

Beacon believes that the opportunity for industry is to develop **whole-house systems** which are resource optimal, affordable and usable across a lifetime. How can you build a house that performs well, stands the test of time and minimises the need for more complex systems? Taking a whole-house approach means that systemic problems are likely to be addressed, rather than the less resource-efficient approach of adding a piece of technology to address the symptoms of a problem – rather than the cause.

The Waitakere NOW Home® design outperformed the alternative designs because its design and materials were a sound long term solution, based on simple principles of passive solar design, and affordable not just to build but over its life cycle: good natural light, passive ventilation, passive solar heating and good heat retention.

Manufacturers need to focus on developing products which provide high performance and which perform well in combination with other products, rather than looking at their particular products in isolation. Addressing the durability and life expectancy of materials and products will also reduce the amount and impact of maintenance.

# 3.2 Creating a robust LCA framework for New Zealand

The outcomes of LCA studies and the environmental performance of the products cannot be fairly assessed without an agreed framework for LCA in New Zealand. Beacon believes that it is in industry's interest to develop a shared understanding of how LCA should be applied given New Zealand conditions. A collaborative effort to develop a credible independent nationally agreed framework for LCA will create a level playing field to support manufacturers in measuring and demonstrating the environmental impact of their innovations.

### *3.2.1 Agree on consistent system boundaries*

LCA methodology involves drawing a clear boundary around the system (system boundary) which is the subject of the analysis. In a comprehensive analysis, the system boundary will extend from primary resource extraction and processing of raw materials through to manufacture, delivery, and use, and finally on to disposal in landfill, (as in a cradle-to-grave analysis), or ultimately from primary extraction, processing, use and then to re-use as products are re-used rather than being consigned to landfill (cradle-to-cradle).

Internationally agreed frameworks (ISO 14040 and ISO 14044) set out the generic steps which must be carried out in a robust LCA study and require all stages of the life cycle to be included.

However, the definition of system boundaries varies for different assessments, depending upon the availability of data and the focus of the assessment. At a minimum, the product stage (cradle-to-gate) is covered, including:

- Extraction of raw materials and biomass production;
- Manufacturing of the product;
- Generation of the energy input, including the production of the energy itself;
- Production of ancillary materials or pre-products;
- Packaging;
- Transportation up to the production gate and internal transport;
- Recycling of materials, including their collection and transport from the system border of the previous system to the production site;
- Waste management processes during the product stage until final waste deposition.[10]

[10] *Nebel, B. (2006)*

The Waitakere NOW Home® LCA was unique in that it set the system boundary around the life cycle of a house; however, even then it excluded the installation and deconstruction of the house.  Furthermore, evaluation of the impact of various products used in the building systems within the house is limited by the system boundaries used to evaluate each of those products in turn – the impacts of wood, for example, are evaluated on a cradle-to-gate basis, excluding the impact of sending treated timber to landfill.  These system boundaries were only a component of what is regarded as best practice by international standards.

Variations between system boundaries from cradle-to-gate, to cradle-to-grave, to cradle-to-cradle can make LCA studies difficult to compare.  To compare the environmental impacts of competing products and building systems on a level playing field, the same economic processes need to be taken into account.  Beacon believes a New Zealand industry agreement on the basis for setting system boundaries would facilitate greater use of LCA studies to enable objective selection of building products and systems which have the least environmental impact.

Setting a system boundary to include downstream impacts is also an important way to reflect the true whole-of-life impact of a house.  In the same way as operational costs must be added to the capital cost of building a home to get a whole-of-life cost of the building, operational and construction environmental impacts must be considered together to see the environmental impact of the home over its whole life.  Ultimately system boundaries will need to include re-use at end of product life (cradle-to-cradle).


### 3.2.2 *Select environmental impact categories that are relevant for New Zealand*

The Waitakere NOW Home® case study applied only five environmental impact categories which were considered on an equal basis. This choice was dictated by availability of data and methodology for alternative categories.

In comparison, the UK's Building Research Establishment (BRE) uses 13 environmental impact categories[11].

| BRE environmental impact categories | What the category measures | Environmental categories used for Waitakere NOW Home study |
|---|---|---|
| Climate change | Global warming or greenhouse gas emissions | Global warming potential |
| Water extraction | Mains, surface and groundwater consumption | |
| Mineral resource extraction | | |
| Stratospheric ozone depletion | Emissions of gases that destroy the ozone layer | |
| Human toxicity | Pollutants that are toxic to humans | |
| Ecotoxicity to freshwater | Pollutants that are toxic to freshwater ecosystems | |
| Nuclear waste (higher level) | High/intermediate-level radioactive waste from nuclear energy industry | |
| Ecotoxicity to land | Pollutants that are toxic to terrestrial ecosystems | |
| Waste disposal | Materials sent to landfill or incineration | |
| Fossil fuel depletion | Depletion of coal, oil or gas reserves | |
| Eutrophication | Water pollutants causing algal bloom | Eutrophication potential |
| Photochemical ozone creation | Air pollutants that react with sunlight and $NO_x$ to produce low-level ozone | Photochemical ozone creation potential |
| Acidification | Emissions that cause acid rain | Acidification potential |
| | | Energy consumption |

[11] *Anderson et al. (2009)*

BRE not only use a wider range of impact categories, they also weight the categories in order to represent the relative importance of the different impact categories.

Figure 4 shows the relative weightings established by BRE in 2006. For example, climate change is considered the most important category, followed by water extraction.

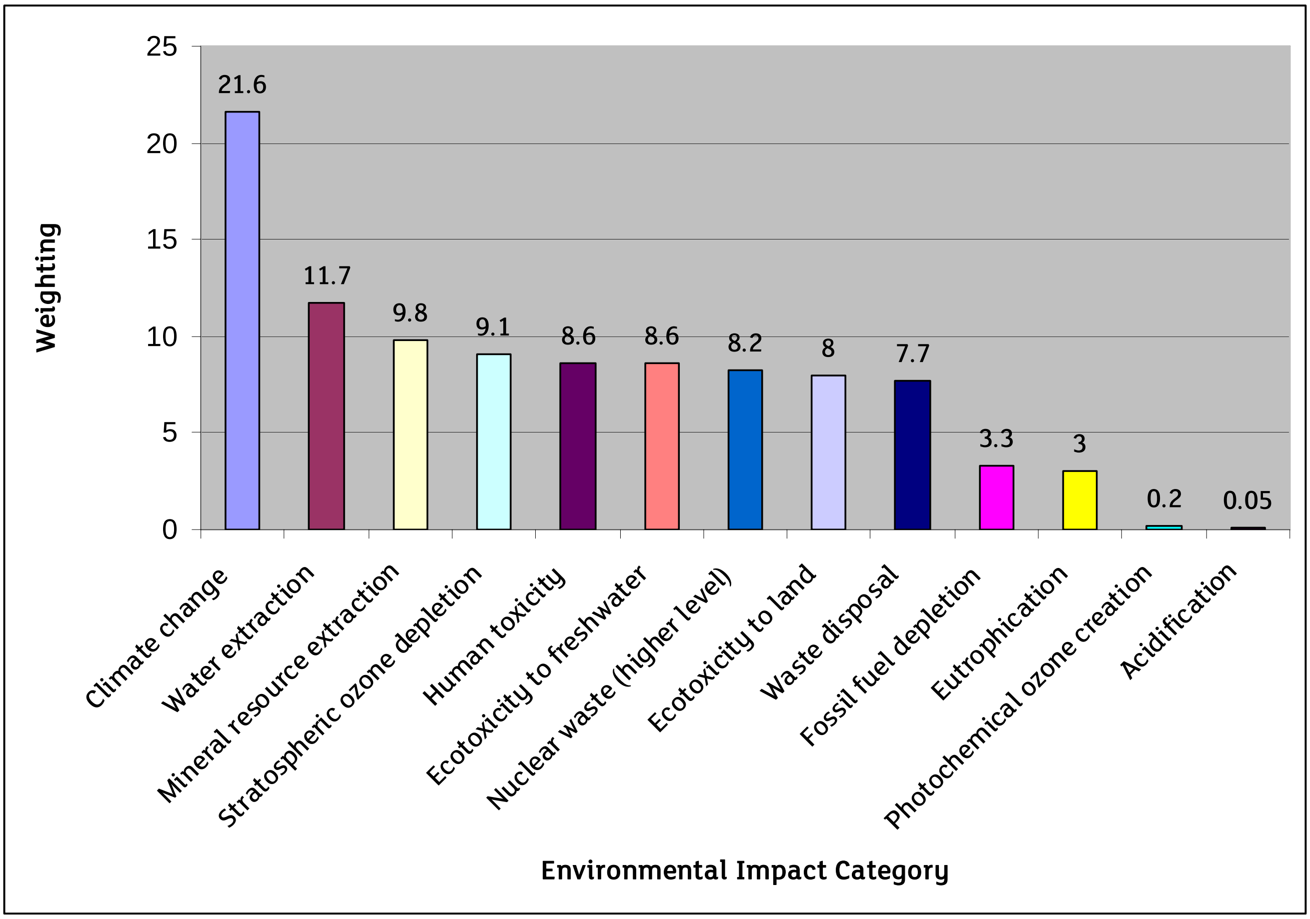



***Figure 4: BRE final weightings for environmental impact categories***[12]

Since there is no purely scientific basis for assessing the relative importance of impacts such as climate change and stratospheric ozone depletion, weighting factors for these different impacts must be derived, with local conditions and environmental concerns a major driver. It is imperative that research, government and industry collaborate to establish and agree on an appropriate set of environmental weightings for New Zealand.

[12] *Anderson et al.. (2009) p.15*

Beacon notes that some of the eight categories not used in the Waitakere NOW Home® LCA may be very pertinent to New Zealand conditions. Water extraction, human toxicity, ecotoxicity to land and freshwater and waste disposal are significant environmental issues in New Zealand, and Beacon would like to see these prioritised in future LCAs. Lack of available data sets and methodologies restricted the Waitakere study's choice of categories, some of which have not been given high weightings in overseas studies and which are unlikely to be regarded as significant issues within the New Zealand environment.

Discussion within industry and the research sector can define what categories are best for the New Zealand situation. Beacon looks forward to future life cycle analysis based on environmental impact categories that are relevant to New Zealand.

### *3.2.3 Address the availability of New Zealand data*

As with all studies of this kind, it is important to be transparent about limitations. The quality of the LCA depends on the quality of the data sources. Actual, fact based data which is measured on site provides high quality results.

While Waitakere NOW Home LCA case study was able to make use of the existing set of New Zealand data, it still needed to be significantly augmented by international sources. Beacon looks forward to a time when studies of this kind rest on a strong foundation of New Zealand-specific data-sets.

However, given the clear message that the operation / maintenance phase of the house bears 80-90% of the environmental impact in the selected impact categories, the quest for New Zealand data should be tempered with commonsense. Comparable New Zealand data for the most common building materials which form the bulk of our homes' construction (timber, steel, concrete, plasterboard, paint) is important. The need for New Zealand data for less commonly used materials or those with smaller mass contributions is less clear.

# 4 Appendix A: Life cycle assessment: An introduction

### *What is Life Cycle Assessment (LCA)?*

It is a technique for systematically evaluating the environmental impacts of a product or service though all the 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 called “cradle-to-grave”.

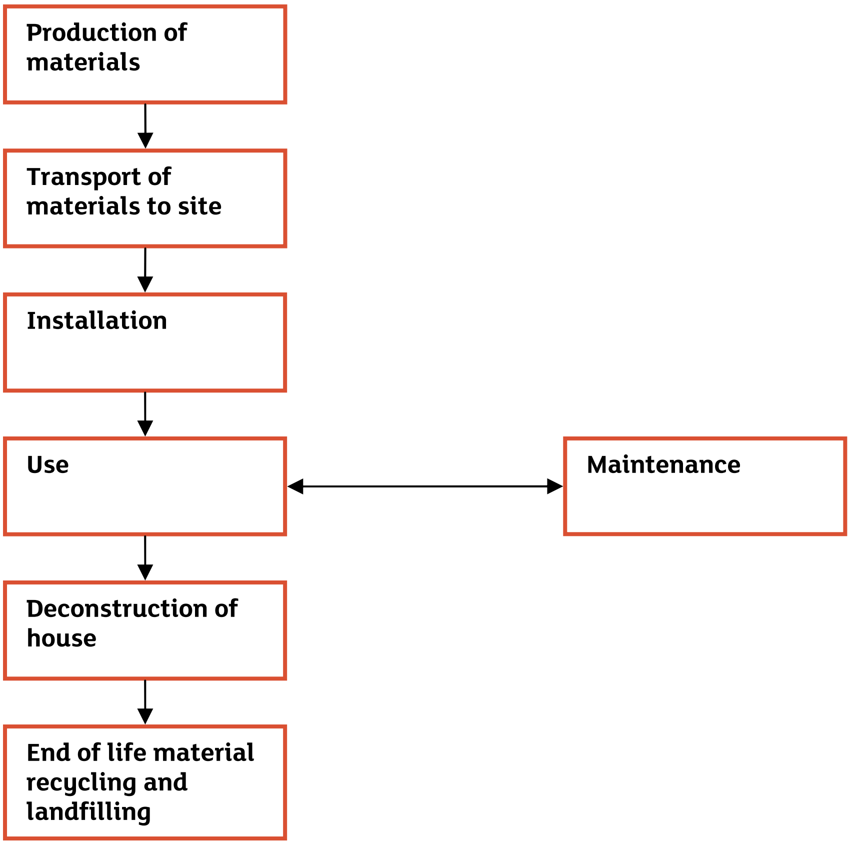



*Figure 5: Life Cycle of a building*

When applied to a building, LCA studies the environmental aspects and potential impacts throughout a building’s life from raw material acquisition through construction, use, deconstruction and disposal.

### *Why use Life Cycle Assessment?*

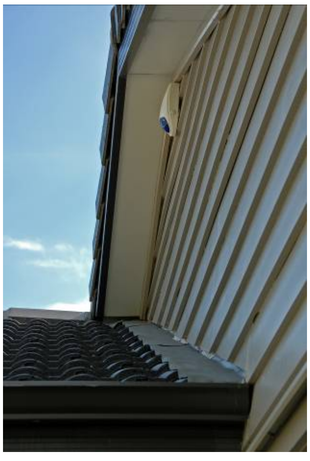
In the building industry, LCA can be used for building improvement and building design by identifying environmental hot spots in building construction, use and disposal. Manufacturers use LCA to improve production processes and product design, as it can also identify hot spots in upstream and downstream processes, such as in the extraction or manufacture of a product, or during the life of the building. For example, improving the durability of cladding product might require a higher environmental cost in the production stage, but lead to significant savings over the whole lifetime of a house by reducing the need for replacement.

### *Looking at a building as a system*

The key concept in LCA is the systems approach. This means on the one hand to look at the whole life cycle of a building material from cradle to grave and on the other hand to focus on the function rather than the material. Rather than looking at a certain mass of material, it looks at the function or the service which is provided by a certain product.

The definition of a functional unit is therefore crucial - it is the basis for the environmental assessment and it describes the system for which an LCA study is carried out. Rather than looking at a certain mass of material it looks at the function or the service which is provided by a certain product. In a building context that means that the emphasis shifts from the product level to building component level.

For example, instead of comparing 1 tonne of concrete with 1 tonne of timber, the functional unit, i.e. the basis for a comparison, would be “one square metre of an external wall for a one storey residential building for a 50 year period”. The respective masses of timber and concrete would be calculated on this basis. And as different additional materials are required for a timber framed wall (internal and external claddings, insulation material, building paper, etc) compared to a concrete wall, these additional materials have to be included as well[13].



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[13] *Nebel (2007)*

### *The steps of a Life Cycle Assessment*

The AS/NZS ISO 14040 and 14044 standards define the generic steps which have to be taken when conducting an LCA:

1) Defining the goal and scope of the LCA study.
2) Inventory Analysis: collecting data and calculating detailed material and energy balances. All quantities of material and energy inputs, and product and emission outputs to air, water, and land are compiled into one inventory which was then used as an input into the life cycle impact assessment.
3) Impact Assessment: translating the results of the inventory analysis into environmental impacts (e.g. global warming, acidification).
4) Interpretation, conclusions and recommendations.

These can be represented as shown in Figure 6. In practice, LCA involves a series of iterations, as its scope is redefined on the basis of insights gained throughout the study.

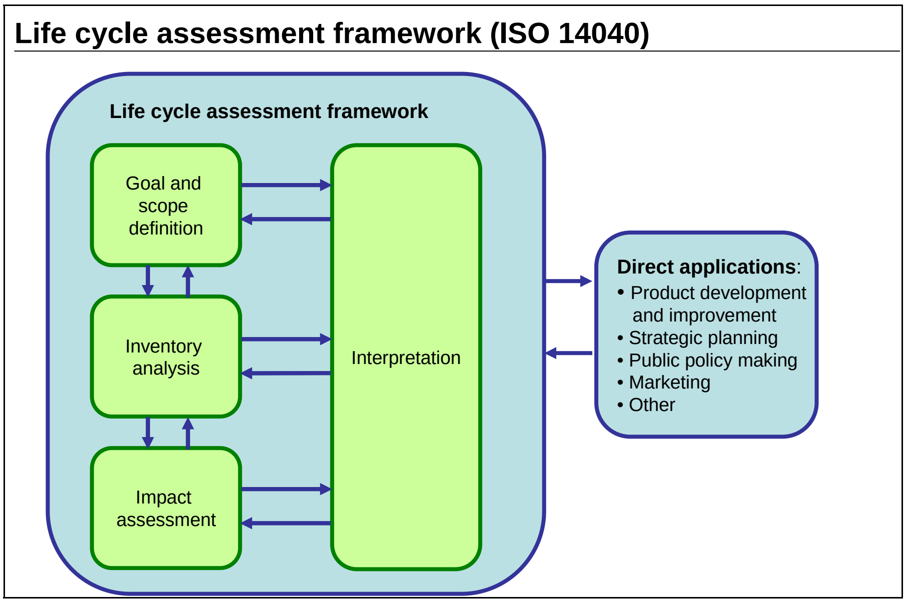



*Figure 6: LCA framework (ISO 14040)*

### *Systems boundary*

The methodology involves drawing a boundary around the system (system boundary) under analysis and quantifying the inputs and outputs across this boundary. Within the system, a number of discrete unit processes are identified, and input-output analysis is undertaken for each unit process (including transportation).

### *Areas of environmental impact*

The systems approach is applied to the impact assessment of an LCA as well, by taking a number of different environmental impacts into account. The results are not restricted to the impact on climate change and energy use.

# 5 Appendix B: Glossary[14]

**Acidification Potential** – Acidification refers to acid deposition from the atmosphere, mainly in the form of rain. Emissions of SO2 and NOx can result in strong and damaging acids. Although there is currently no evidence of acid rain in New Zealand[15], SO2 and NOx emissions are closely monitored and regarded as an important issue in New Zealand.

**Allocation** – Allocation is the partitioning of the environmental impacts of a unit process to the product system under study according to how much the products cost/weigh. When more than one product is produced from a process, it is necessary to divide the environmental impacts from the process between the products. Two methods are available, either allocation or system expansion. The ISO 14040 –series suggest using system expansion whenever possible, and where it is not possible allocation can be used instead. The principles behind the allocation in a specific project should be presented each time an LCA is conducted.

**Embodied energy** is the energy consumed by all processes from extraction of raw materials through to the end product

**Energy consumption** is the amount of site consumption, plus losses that occurs 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

**Environmental hot spots** - These are systems which contribute the most to the environmental impact of a home.

**Environmental Product Declaration** - An Environmental Product Declaration presents quantified environmental data for a product based on information from a life cycle assessment (LCA) according to the ISO-standards for LCA. An Environmental Product Declaration is often voluntarily developed and is valid for a specified period. It must be certified by an independent authority. It typically has three parts – a product or company description, details on environmental performance and details of the accreditation organisation. An Environmental Product Declaration provides verifiable accurate, comprehensive environmental information for the products and their applications.

[14] *Nebel et al. (2009)*
[15] *Nebel et al. (2009) p.38*

**Environmental Profile** - The Environmental Profiles Methodology is a standardised method of identifying and assessing the environmental effects associated with building materials over their life cycle. It establishes a set of common rules and guidelines for applying Life Cycle Assessment (LCA) to construction products, to produce Environmental Profiles. This enables a 'level playing field' comparison of competing building materials.

**Eutrophication Potential** – Eutrophication occurs when there is an increase in the concentration of nutrients in a body of water or soil, occurring both naturally and as a result of human activity. It may be caused by the run-off of synthetic fertilisers from agricultural land, or by the input of sewage or animal waste. It leads to reduction in species diversity, often accompanied by massive growth of dominant species, for example "algae bloom".

**Functional unit** - The functional unit defines the quantification of the identified functions or performance characteristics of the product. Rather than looking at a certain mass of material it looks at the function or the service which is provided by a certain product.

The functional unit of a building product is based on:

- The quantified, relevant functional use or performance characteristics of the construction product when integrated into a building, taking into account the functional equivalent of the building;
- The product's service life under defined in-use conditions.

The primary purpose of the functional unit is to provide a reference by which, for a building product or service, the material flows (input and output data) of an LCA and the additional information are normalised, allowing comparison of LCA data.

**Global Warming Potential** (over 100 years) - Increasing amounts of greenhouse gases, such as carbon dioxide or methane, enhance the natural greenhouse effect and lead to an increase in global temperature. During the 20$^{th}$ century, the average global temperature has increased by about 0.6°C due to the enhanced greenhouse effect.

**Input/Output** – In LCA methodology Input is defined as materials or resources used in a process, e.g. electricity, sand or water and Output is a product, material or energy which leaves a unit process, e.g. cement, particle board.

**Life Cycle Assessment** – ISO 14040 defines LCA as:
"… a technique for assessing the environmental aspects and potential impacts associated with a product throughout it's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal, 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."

**Life Cycle Inventory** – This describes both the inventory analysis process and the resulting database. Inventory analysis involves the collection of data related to the functional unit, modelling of the product system, and description and verification of data. The database provides information about all inputs and outputs in the form of elementary flows to and from the environment from all the unit processes involved in the study. The relevant inputs and outputs of the analysed product system are quantified and produced as a table.

**Photochemical Ozone Creation Potential** (POCP) – POCP is an indicator of the ability of a Volatile Organic Compounds (VOC) to contribute to photochemical ozone formation. It is a measure of the reactivity of an organic compound with hydroxyl radicals and subsequent formation of ozone. As VOCs vary in their reactivity they therefore contribute differently to the formation of ozone. POCP is a basic measure to compare reactivities of volatile compounds.

**System boundary** - The system boundaries determine which unit processes are included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase. The system boundary decides where a life cycle begins and ends: for example, life cycle usually begins at the extraction point of raw materials and energy carriers from nature, and ends with waste generation and/or heat production.

# 6 Appendix C: Input / output data for the LCA

***Waitakere NOW Home®:*** Material quantities have been calculated for the Waitakere NOW Home® based on invoices for work done and personal communications with those involved in the project. The invoices provided a varying degree of data quality ranging from: material dimensions and quantity purchased through to only labour costs. Where unavailable, some material quantities had to be calculated.

***Alternative NOW Home® designs:*** The building systems within the alternative NOW Home® designs were also modelled on Scion's Exemplar House as a quality check to ensure material quantities were as accurate as possible.

### *Material Quantities*

Figure 7 presents the percentage contribution, by mass of each system in the Waitakere NOW Home®. The foundation system has the greatest contribution to total mass (78%), followed by the roof (13%), external wall (4%) and internal wall (4%) systems.

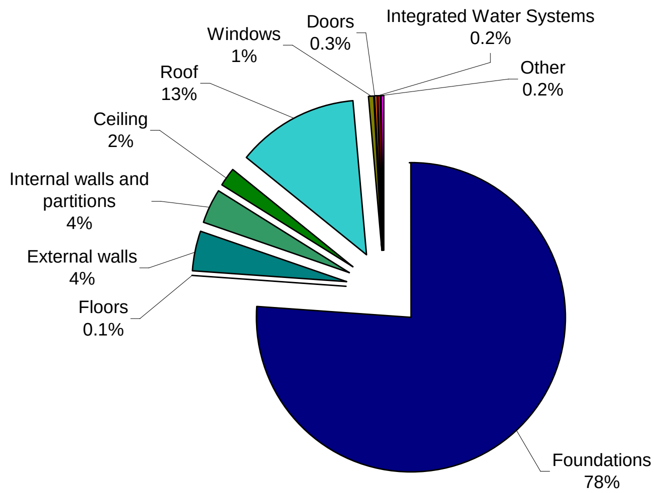



***Figure 7: Percentage contribution, by weight of building systems in the Waitakere NOW Home®***

Figure 8 presents the percentage contribution, by weight of materials in the Waitakere NOW Home®.

Concrete accounts for a high proportion of the mass of the Waitakere NOW Home®, with a 46% contribution. The gravel in the hardfill is the next biggest contributor with 24%. Concrete roofing tiles (8%), timber (8%), sand (7%), and gypsum board (5%), are the other significant contributors to total mass.

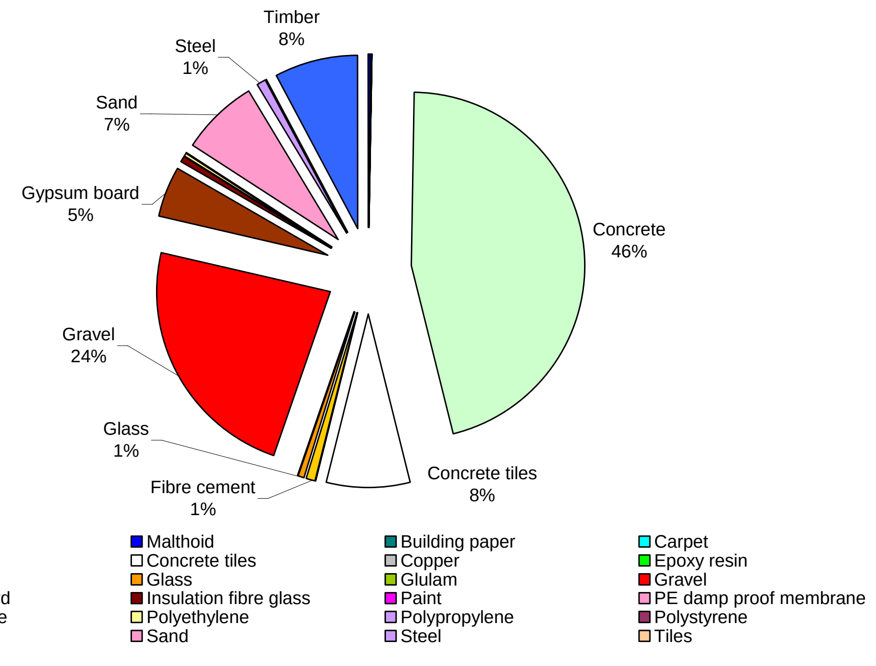



*Figure 8: Percentage contribution, by weight of materials installed in the Waitakere NOW Home® (only materials contributing 1% or more have been labelled)*

### *Material Waste*

Data from material waste monitoring of the Waitakere NOW Home® construction was used. The construction of the Waitakere NOW Home® generated 2,448kg of material wastes. Table 2 presents the weights of waste materials generated.

***Table 2: Final weight of waste materials generated through construction of the Waitakere NOW Home®[16]***

| Material | Final weight (kg) |
|---|---|
| Steel scrap | 69 |
| Miscellaneous (e.g. concrete tiles, gravel, fibrecement etc.) | 543 |
| Cardboard and paper | 45 |
| Recyclable plastic #1,2 | 2 |
| Recyclable plastic #6 | 5 |
| Plaster board | 705 |
| Treated timbers | 335 |
| Untreated timber (incl. engineering board) | 122 |
| Hazardous materials | 6 |
| Concrete and mortar | 108 |
| Clear plastic wrap | 9 |
| Bottles and cans | 9 |
| Miscellaneous and large chunks of concrete | 511 |

### *Transport*

An average transport distance of 50km was used for all materials transported to the building site. Though the majority of building materials are sourced from the Auckland region, the greater travelling distance for timber, from harvested forest to the site, increases the average travelling distance for the materials. Szalay and Nebel[17] showed that transport has a minimal contribution to the overall impact, and a more accurate calculation of distances travelled per material would therefore not alter results significantly.

[16] *There is a discrepancy in figures between total weight of materials and total final weight due to the moisture content.*
[17] *Nebel and Szalay (2006)*

### *Maintenance*

Maintenance activities including everyday measures (repairs or decorating) and heavy maintenance (restoration or replacement of building systems) were included in the study. The base scenario lifetime for the Waitakere NOW Home® was 100 years. A lifetime of 50 years was also modelled for the Waitakere NOW Home®, in order to identify the variation in impact for different building lifetimes. Calculations of the number of replacements in the life cycle were prorated.

### *Use Phase*

The reticulated energy consumption of the Waitakere NOW Home® was monitored for two years (see Table 3) and included all energy end-uses. However, this study concentrated on energy used for heating, lighting and hot-water as they reflect the design of the Waitakere NOW Home®, rather than the behaviour of the residents[18]. Heating, lighting and hot water was calculated at 30% for Year 1 and 35% for year 2[19]. Note that heating was minimal in the Waitakere NOW Home which required space heating on only a few days per year.

***Table 3: Waitakere NOW Home® annual reticulated energy use for years 1 and 2 and weighted average for both years[20]***

| Waitakere NOW Home® | Total annual reticulated energy use (kWh) | HL+HW annual reticulated energy use (kWh) | Lifetime HL+HW reticulated energy use (kWh) | |
|---|---|---|---|---|
| | | | 50yrs | 100yrs |
| Year 1 | 7,400 | 2,220 | 111,000 | 222,000 |
| Year 2 | 8,500 | 2,975 | 148,750 | 297,500 |
| Weighted average | 8,133 | 2,723 | 136,150 | 272,300 |

[18] *It can be argued that energy for space heating can be arbitrary due to people's personal preferences (i.e. some people will heat their homes and some will not); however for this study it was assumed that heating is not behaviour related and most people will prefer their home to be at a certain temperature. The heating energy demand to reach this temperature is dependent on the design of the building and the building envelope.*

[19] *Pollard et al. (2008) section 3.2 Energy end uses*

[20] *Pollard et al. (2008)*

### *Alternative NOW Home® designs and locations*

Operational energy data - for heating only - for the alternative NOW Home® designs were calculated using the Annual Loss Factor tool (ALF) developed by BRANZ. The heating energy demand reflected the amount of energy required to reach and sustain the living space temperature at 18°C in morning and evening hours. These time periods were chosen because the majority of household occupants are present in the building at these times.

This tool was also used to calculate the heating energy demand for each NOW Home® design in each climate zone (Auckland, Wellington, Christchurch), including the Waitakere NOW Home®.

### *End of Life*

The impacts from the end of life stage are minimal compared to total life cycle impact[21]. Therefore, apart from aluminium window frames, it was assumed all materials disposed off at the end of the life of the Waitakere NOW Home® were sent to landfill. The end of life impact reflects the transport, based on an average of 50km, and processing of waste materials in landfill.

Given the initial embodied impact of aluminium window framing is generally high and recycling is a viable option, it was assumed the aluminium window framing would be recycled at the end of life stage and the impact savings of recycling were deducted from the initial embodied impact of the aluminium. Although concrete roofing tiles and timber weatherboards could be reused or recycled, lack of data on these options led to the assumption that they would be landfilled.

[21] *Nebel and Szalay (2006)*

# 7 Appendix D: Detailed Findings

This Appendix presents the detailed data for each area of analysis.

The case study considered the relative impact of each building system in order to identify the environmental hot spots in the Waitakere NOW Home®. This section highlights the systems and materials that account for a significant contribution to the construction impact of the Waitakere NOW Home®. The analysis identifies both materials that cause a high proportion of impact in each system, and materials that cause a high proportion of impact in the Waitakere NOW Home®.. The main contributors include foundations, external and internal walls, ceiling, roof, windows and the integrated water system.

The lifetime of the Waitakere NOW Home® in the base scenario was 100 years. However, in order to identify whether difference in lifetime influences the proportion of impact contributed by each life cycle stage of the building, the 100 year lifetime scenario was compared to a 50 year lifetime, reflecting the minimum Code requirements. The main aim was to identify whether the proportion of the combined embodied impact of the construction and maintenance stages decreases in relation to the operational impact as the building life increases.

In addition to the actual design of the Waitakere NOW Home®, the life cycle impacts of four alternative NOW Home® designs were also assessed. Furthermore the operational energy (heating energy demand) of each of these designs, including the actual NOW Home®, was assessed in two alternative climate zones - Wellington and Christchurch. These cities were chosen because they are the other two main cities in New Zealand, and they are in different climate zones. The global warming impact category has been selected to represent the life cycle impact of each NOW Home® design in each climate zone.

These alternative building systems were chosen because they are all common building systems in New Zealand. The aim of the assessment was to compare different New Zealand building systems including the building systems of the Waitakere NOW Home®.

# 7.1 Environmental impact of each building system

### *7.1.1 Overview*

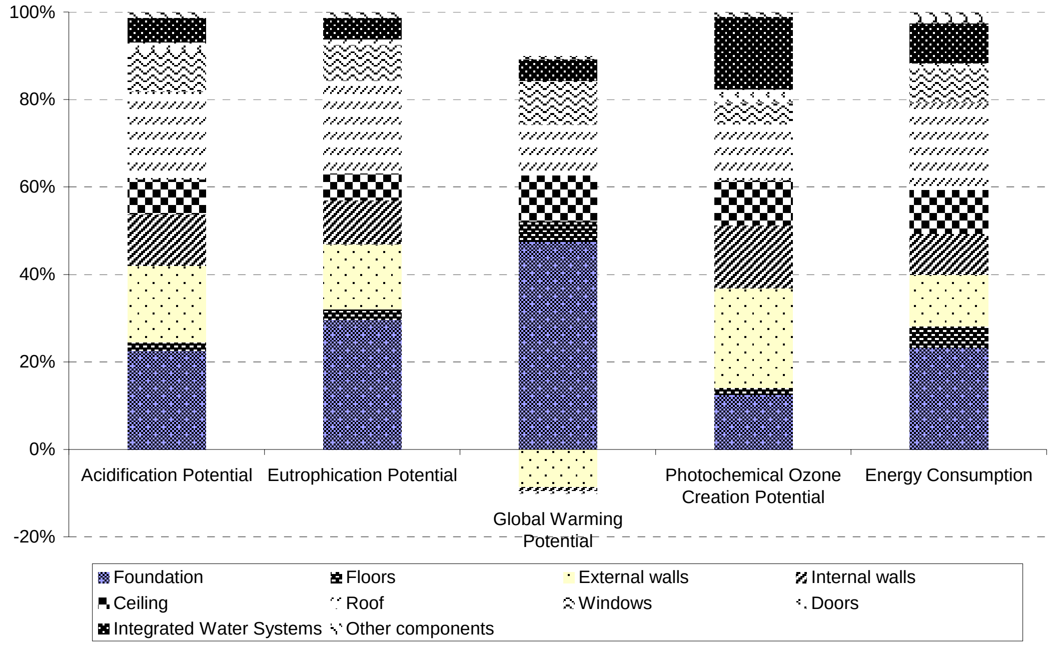



***Figure 9: Percentage contribution to environmental impacts of each building system in the Waitakere NOW Home®***

In Figure 9, the contribution of the building systems is shown by impact category. Building systems consisting largely of wood, such as the external and internal walls, had a net negative global warming potential. This reflects the permanent storage of carbon within the wood when it is landfilled.[22]

The foundation system was the main contributor to each category except photochemical ozone creation potential, and dominated the global warming category, providing 53% of the impacts.

The external walls were the main contributor to the photochemical ozone creation potential impacts, and combined with the internal walls, the wall system dominated the category, accounting for 37% of impact.

The roof system had the next largest contribution accounting for between 11% (global warming potential) to 19% (energy consumption) of the total impact from the building systems.

The integrated water system had a noticeably high photochemical ozone creation potential accounting for 16% of the total impact from the building systems.

*[22] The net $CO_2$ storage is included in the construction impact because it is an inherent property of the timber and should not be associated with the end of life stage. The net $CO_2$ is calculated from the amount of carbon that remains in the landfill permanently, once the decomposition of the timber and release of GHG emissions has ceased.*

### 7.1.2 Foundations

The contribution of the foundation system to the total impact of the materials used in construction ranged from 11% (photochemical ozone creation potential) to 51% (global warming potential). The system accounted for 22% of the embodied energy from construction materials, but also accounted for 78% of the total mass of the Waitakere NOW Home®.

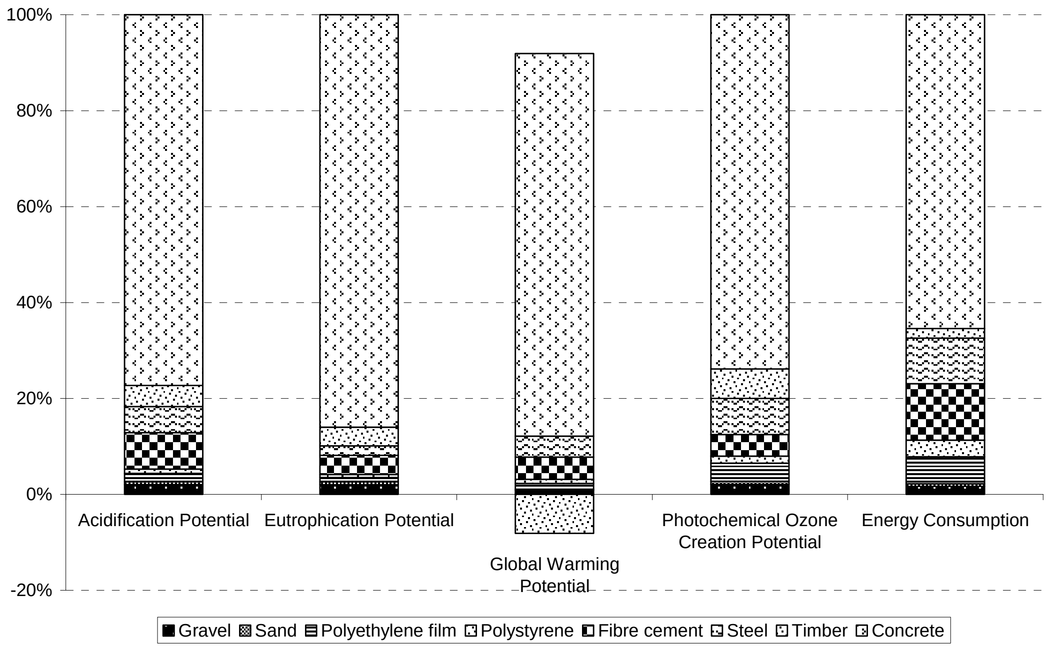



***Figure 10: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® foundation system***

### *Contribution of the component parts of the foundation*

Figure 10 shows the contribution of each material making up the foundation system of the Waitakere NOW Home (concrete slab floor) by environmental impact category.

- Concrete dominated all environmental impact categories from the foundation system, ranging from 65% (energy consumption) to 86% (eutrophication potential). Even when considered in terms of the whole building, concrete accounted for 20% and 14% of the eutrophication potential and embodied energy of the construction impact respectively. However, concrete formed the largest part of the mass of the foundations (59%) and even formed 46% of the mass of the entire house.
- While fibre cement and reinforcing steel were the next largest energy consumers, accounting for 12% and 10% of the embodied energy of the foundations respectively, they formed only a very small part of the total foundation mass (0.5% and 0.7% respectively).
- Polystyrene and polyethylene damp proof course were also products that accounted for significant percentages of the foundation’s total embodied energy, but which formed only a tiny proportion of the foundation’s mass.

### 7.1.3 External walls

The external wall system accounted for between 5.6% (global warming potential) to 20% (photochemical ozone creation potential) of the total construction impact, with a contribution of 4% of the mass of the Waitakere NOW Home®. The external wall system accounted for 11% of the total energy consumption from construction.

#### *Contribution of component parts of external wall system*

Figure 11 shows the contribution of each material making up the external wall system of the Waitakere NOW Home® (weatherboards) by environmental impact category.

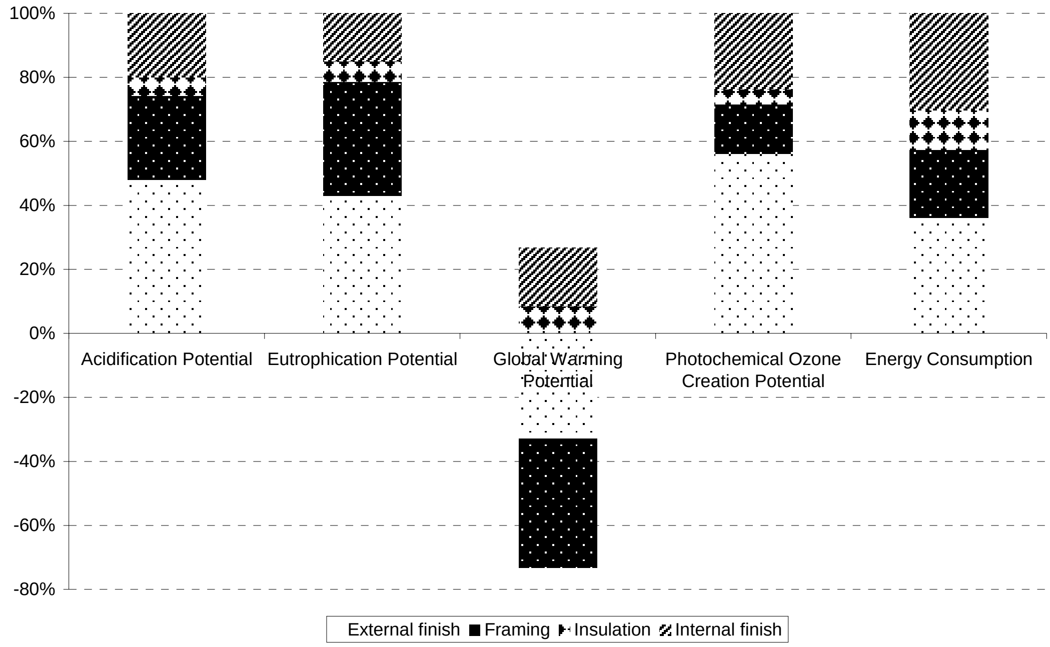



***Figure 11: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® external wall system***

- The external and internal finish accounted for the largest proportion of embodied energy of the external wall system with 36% and 30% respectively. Timber cladding and paint were the biggest contributors to energy consumption (49% and 26%, respectively), and timber accounted for 92% the mass of the external finish. Paint dominated the photochemical ozone creation potential and acidification of the external finish (68% and 57% respectively), but formed only 3% of the mass of the external finish of the system.
- Overall, paint, despite accounting for only 1.7% of the mass, was a major contributor (56%) to the total photochemical ozone creation potential of the entire external wall system. On the scale of the entire Waitakere NOW Home® paint accounted for 12% of the total construction photochemical ozone creation potential and only 0.07% of total mass.
- The timber component of the weatherboards and framing in the wall system led to a net negative global warming potential, due to the stored carbon within the timber.
- Glass wool insulation accounted for 12% of the total embodied energy of the wall system but only 2.5% of the mass of the wall system. This amounts to 1.3% of the total embodied energy of the building and 0.1% of the mass of the Waitakere NOW Home®.

### *7.1.4 Internal walls*

The internal wall system accounted for between 8% (eutrophication potential) and 13% (photochemical ozone creation potential) of the total construction impact, and 3.8% of the mass of the Waitakere NOW Home®.

### *Contribution of component parts of internal wall system*

Figure 12 shows the contribution of each material making up the internal wall system of the Waitakere NOW Home® (painted plasterboard) by environmental impact category.

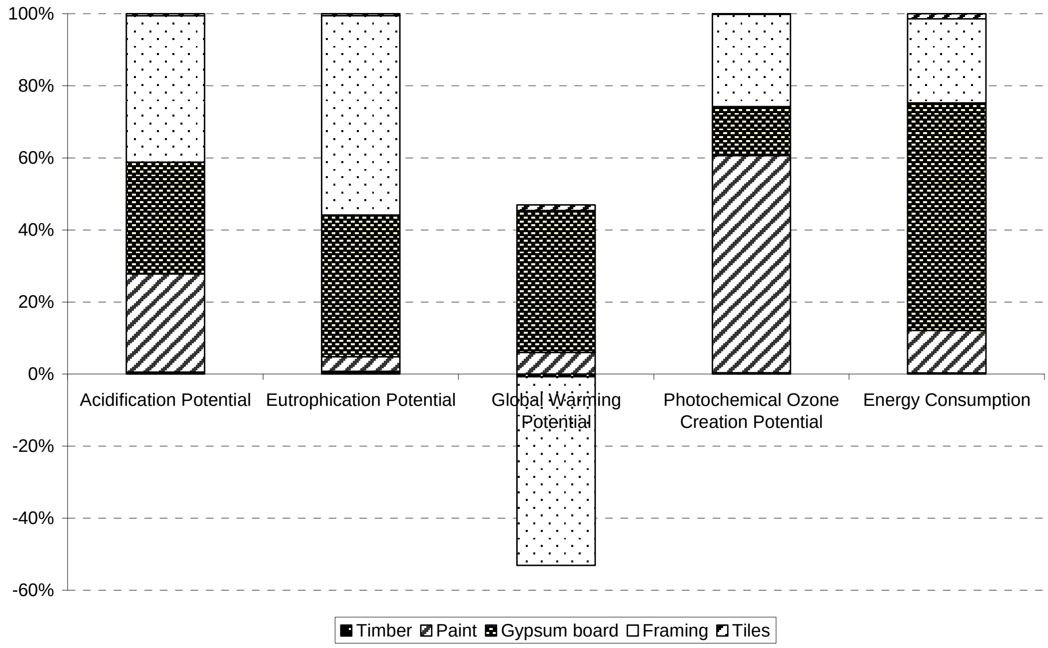



***Figure 12: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® internal wall system***

Paint was the main contributor to the photochemical ozone creation potential of the internal wall system (60%), despite being only 1.3% of the mass of the system. On the scale of the whole building, paint accounted for 8% of the total construction impact but only 0.05% of total mass.

Gypsum board accounted for the greatest single contribution to the embodied energy of the internal wall system (63%), but also the largest proportion (55%) of the mass of the system.

Framing installed in the internal wall system formed a high proportion of the eutrophication potential of the system (55%). However, framing formed 41% of the mass of the system, and again timber framing also led to a large net negative global warming potential.

### *7.1.5 Windows*

The percentage contribution of the windows to the total construction impact ranged from 5% (photochemical ozone creation potential) to 11% (global warming potential), with a mass contribution of 1% of the Waitakere NOW Home®.

### *Contribution of component parts of window system*

Figure 13 shows the contribution of each material making up the window system of the Waitakere NOW Home® (aluminium-framed double glazing) by environmental impact category.

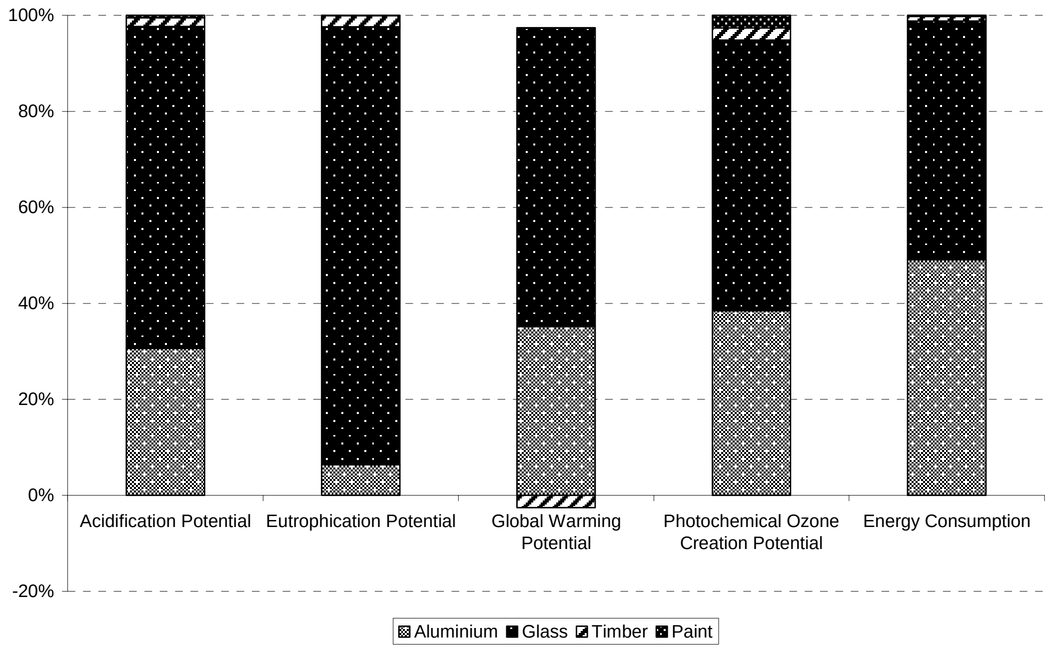



***Figure 13: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® window system***

- Glass dominated all the impact categories, ranging from 50% (energy consumption) to 91% (energy consumption), and contributed 70% to the mass of the window system. Glass accounted for 6% of the total eutrophication potential of construction and 0.5% of the total mass of the Waitakere NOW Home®.
- Aluminium accounted for 49% of the embodied energy of the window system, accounting for 22% of the mass of the system. This amounts to 4% of total construction energy consumption and 0.2% of the mass of the building.

### 7.1.6 Ceiling

The contribution of the ceiling system to the construction impact of the building ranged from 5% (eutrophication potential) to 12% (global warming potential), and accounted for 2% of the mass of the Waitakere NOW Home®.

#### *Contribution of component parts of ceiling system*

Figure 14 shows the contribution of each material making up the ceiling system of the Waitakere NOW Home® (painted plasterboard) by environmental impact category.

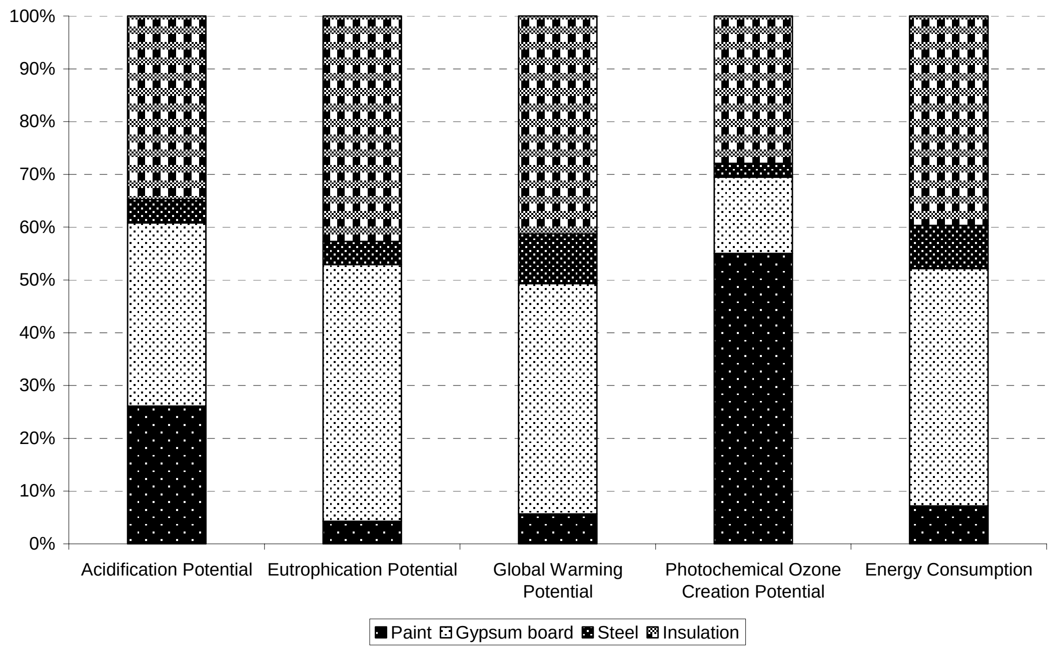



***Figure 14: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® ceiling system***

- The majority of the energy consumption, eutrophication and global warming potential of the ceiling is attributed to gypsum board and insulation. Together, gypsum board and insulation account for 85% of the energy consumption, and a similar proportion for eutrophication and global warming potential. Gypsum board forms the majority of the ceiling mass (78%), whereas insulation accounts for 14%.
- Paint accounts for a large proportion of the acidification and photochemical ozone creation potential (26% and 55% respectively).
- The steel nail-up battens account for 8% and 9% of the ceiling energy consumption and global warming potential respectively, and 5.6% of the mass of the ceiling system.

### 7.1.7 Roof

The roof system accounted for between 12% (photochemical ozone creation potential) and 19% (energy consumption) of the total construction impact. Roofing dominates each impact category especially energy consumption (62%).

### Contribution of component parts of roof system

Figure 15 shows the contribution of each material making up the roof system of the Waitakere NOW Home® (concrete tiles) by environmental impact category.

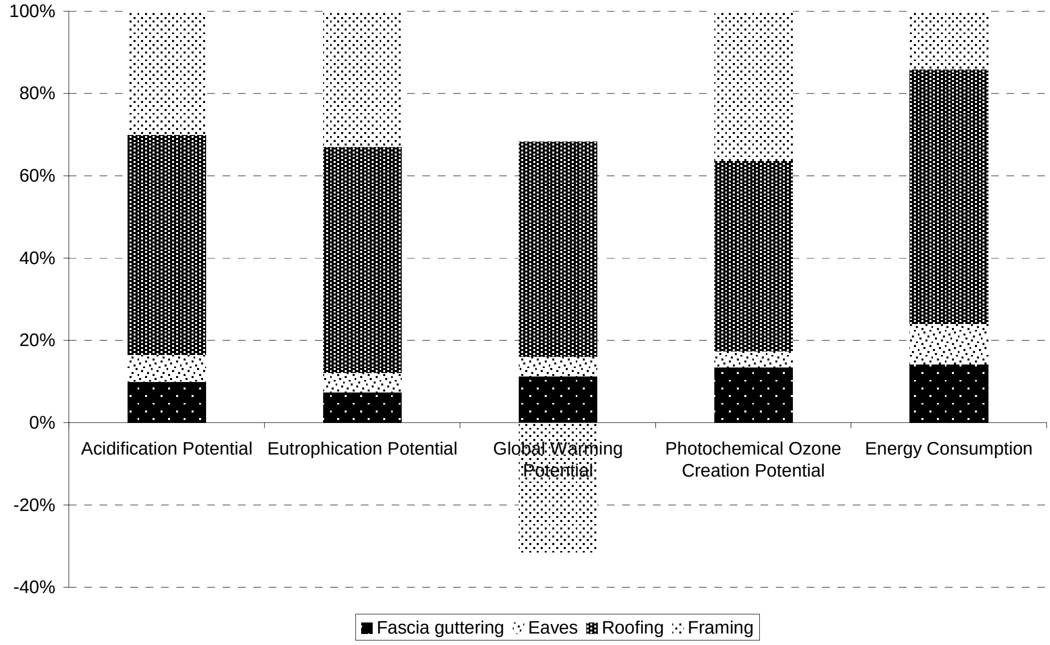



***Figure 15: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® roof system***

- Roofing materials included: concrete tiles, timber battens and building paper, and formed 78% of the mass of the roof system.
- $CO_2$ stored in the timber framing accounted for the greatest net negative global warming potential, while timber components of the roofing materials lower its global warming potential.
- Framing accounted for a relatively large contribution to the acidification potential (30%), eutrophication potential (33%) and photochemical ozone creation potential (36%) of the roof system, and for 18% of the mass of the system. Overall, framing formed 5% of the total construction impact for each category and 1.9% of the mass of the Waitakere NOW Home®

### *7.1.8 Other building systems or components*

The remaining building systems or components that were assessed in this study included the integrated water system, doors, pergola and garage door. Aside from the integrated water system, the other components accounted for a minimal contribution to all impact categories, individually accounting for approximately 1% or less of the embodied energy of the building and less than 1% of the mass of the Waitakere NOW Home®. Therefore these components will not be discussed further.

The contribution of the integrated water system to the total impact of the building ranged between 4% (eutrophication potential) to 15% (photochemical ozone creation potential) of the total construction impact. Copper piping and polypropylene down-pipes were included in the assessment of the system. However both piping materials contributed less than 0.5% to the total impact of the building for each impact category and therefore will not be discussed further.

The polypropylene rainwater tank contributed over 90% of the impact of the integrated water system. The rainwater tank accounted for 0.2% of the mass of the Waitakere NOW Home® but accounted for 8.5% and 15% of the embodied energy and photochemical ozone creation potential of the building respectively.




# 7.2 The effect of lifetime on impacts

The lifetime of the Waitakere NOW Home® in the base scenario was 100 years. However, in order to identify whether the difference in lifetime influences the proportion of impact contributed by each life cycle stage of the building, an alternative scenario was modelled decreasing the lifetime to 50 years, which reflects the minimum Code requirements.

Figure 16 presents the contribution to each impact category of the life cycle stages for 50 and 100-year lifetimes. As expected, maintenance impact increases as greater quantities of materials are required to maintain the building for a longer lifetime.

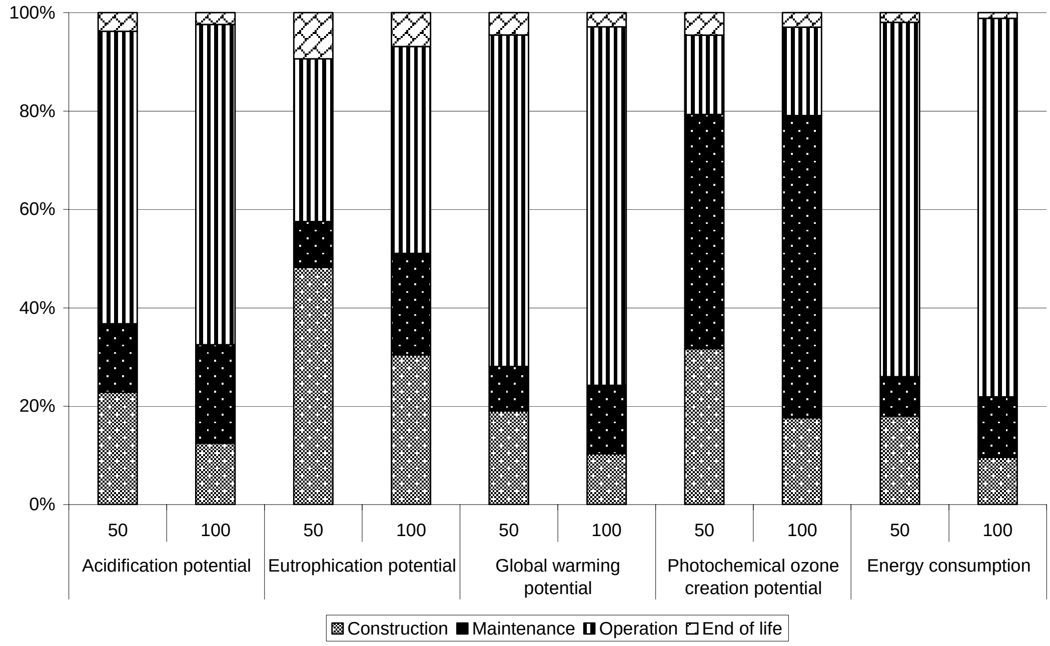



***Figure 16: Percentage contribution to life cycle environmental impacts of the Waitakere NOW Home® with a lifetime of 50 and 100 years***

The impact contribution from maintenance to the photochemical ozone creation potential of the life cycle is large and increases from 48% to 61% from 50 to 100 years respectively. However, the greatest increase is seen in eutrophication potential impact from 9% to 21% from 50 to 100 years respectively.

As the lifetime increases, the contribution of the embodied impact of all materials installed in the building (construction and maintenance related materials combined) to the overall life cycle impact decreases for all impact categories. The longer the Waitakere NOW Home® is in operation, the more the proportion of the total embodied impact of the built-in materials will decrease in relation to the proportion of the operational impact.

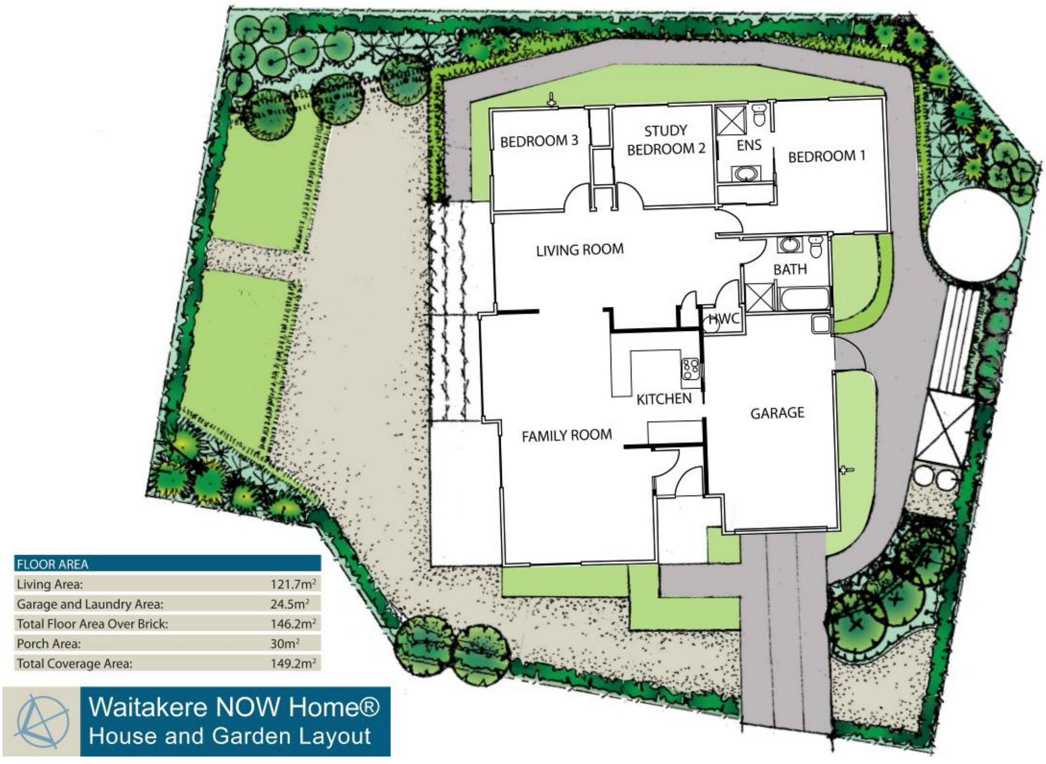
The proportion of the operational impact, for all categories, increases as the lifetime is extended from 50 to 100 years. For example, operational energy consumption increases from 72% to 77% from 50 to 100 years.

# 7.3 Alternative designs

The life cycle impacts of four alternative NOW Home® designs were also assessed and compared with the Waitakere NOW Home®. These were:

- Alternative NOW Home® design 1: Suspended timber floor (with garage concrete slab) instead of insulated concrete slab – other building systems remain the same.
- Alternative NOW Home® design 2: Brick cladding instead of timber weatherboards – other building systems remain the same.
- Alternative NOW Home® design 3: Steel roof instead of concrete tile roof – other building systems remain the same.
- Alternative NOW Home® design 4: Combination of all the above building system changes – other building systems remain the same.

The operational energy for each NOW Home® design in each climate zone was calculated using the Annual Loss Factor tool (ALF) developed by BRANZ. This tool calculates the annual amount of heating energy required to heat and sustain the living space temperature at 18°C during morning and evening hours.



### 7.3.1 Results

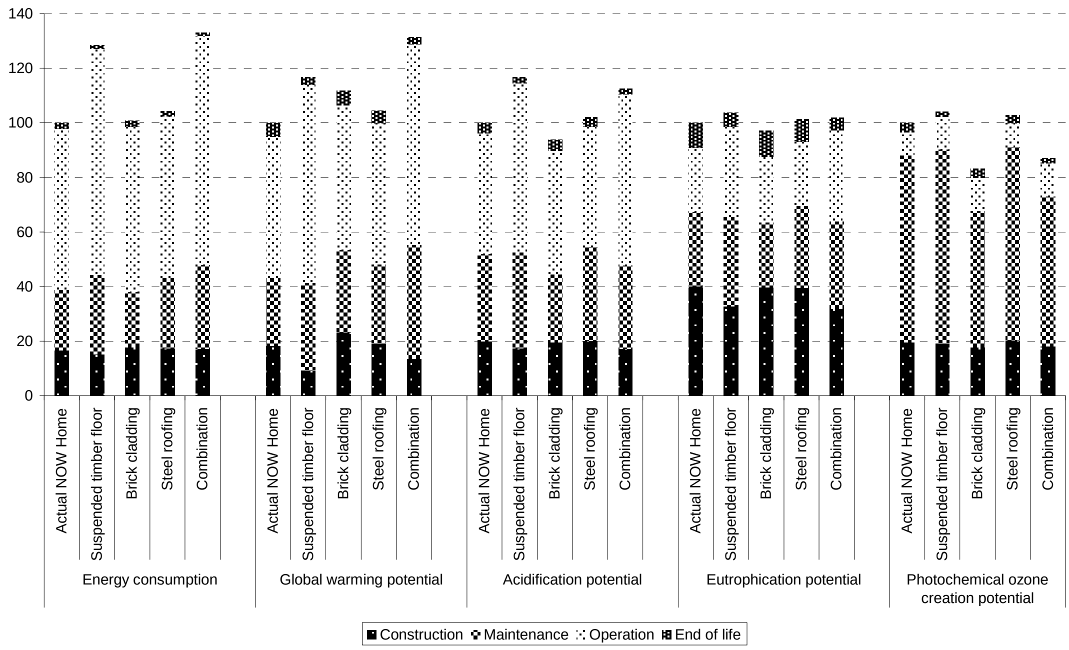



***Figure 17: Comparative representation of the life cycle impact of each NOW Home® design, for each impact category, in Auckland***

In all building design, the operation stage is dominant for energy consumption, global warming potential and acidification potential.

The operational impacts of the actual NOW Home®, and brick cladding and steel roofing NOW Home® designs are similar because they all have a concrete slab foundation. The operational impact for the suspended timber floor and the combination NOW Home® designs, however, have a higher operational impact. This indicates that the design of the foundation/floor system has a strong influence on the heating energy demand of the different NOW Home® designs.

The actual NOW Home® design had the lowest life cycle impact for energy consumption and global warming potential. This reflects the lower operational impact of the concrete slab foundation. With a polished concrete floor acting as a heat sink and good solar design, the Waitakere NOW Home needed very little additional space heating, and therefore reduced energy consumption by 33%.

The maintenance-related photochemical ozone creation potential dominates the life cycle impact for all the NOW Home® designs due to reapplication of paint. The brick cladding and the combination NOW Home® designs have lower values for this impact because no paint is required to maintain the brick cladding. This is also shown for eutrophication potential.

The suspended timber floor NOW Home® design had the lowest construction impact for global warming potential because of the stored $CO_2$ within the timber. However it had the highest operational impact, and a higher maintenance impact due to re-carpeting.

# 7.4 Alternative locations

The operational energy (heating energy demand) of each of the designs, including the actual NOW Home®, was assessed in two alternative climate zones - Wellington and Christchurch. These cities were chosen because they are the other two main cities in New Zealand, and they are in different climate zones. The global warming impact category has been selected to represent the life cycle impact of each NOW Home® design in each climate zone.

The relative life cycle impact of each building design, in each climate zone, is shown in Figure 18. The actual NOW Home® in Auckland is set at 100 and each alternative NOW Home® design in each climate zone is weighted relative to this value.

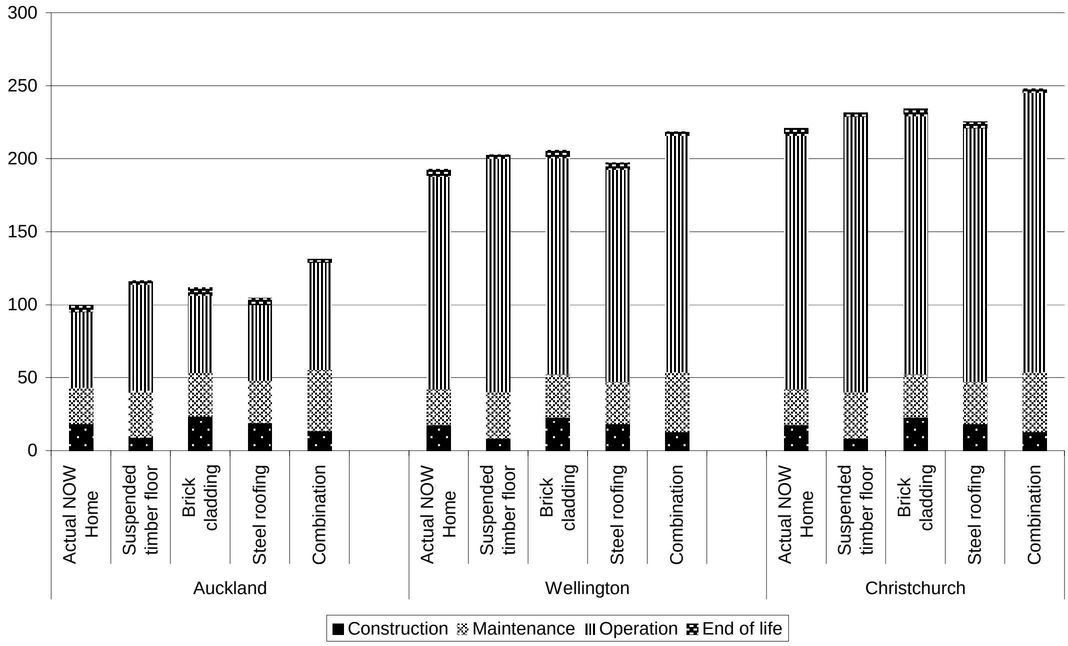



***Figure 18: Comparative representation of the life cycle impact of each NOW Home® design, for each impact category, in each climate zone***

The total life cycle impact increases by around 86% (suspended timber floor) to 94% (brick cladding) from Auckland to Wellington. All the NOW Home® designs had the lowest life cycle impact in Auckland due to lower heating demand.

The operational impact dominates the life cycle impact of each building design in each climate zone. It increases by 120% for suspended timber floors to 183% (actual NOW Home®). The change in operational impact from Wellington to Christchurch is much smaller than the change from Auckland to Wellington.

# 8 Appendix E: Data tables

*Table 4: Density of building materials*

| Building material | Density ($kg/m^3$) |
|---|---:|
| Aluminium | 2,700 |
| Bitumen DPC malthoid (0.001m) | 1,100 |
| Building paper | 0.195$kg/m^2$ |
| Carpet | 2.25$kg/m^2$ |
| Concrete | 2,200 |
| Copper | 8,960 |
| Hydrocoat epoxy sealer | 1.06kg/l |
| Fibre cement | 1,400 |
| Glass | 2,500 |
| Glulam | 500 |
| Gravel | 1,800 |
| Gypsum board | 900 |
| Insulation fibre glass (wall/ceiling) | 10.2/13.5 |
| Paint | 1.3kg/l |
| Particle board | 600 |
| PE damp proof membrane | 900 |
| Polycarbonate | 1,200 |
| Polypropylene | 946 |
| Polystyrene | 16 |
| PVC | 1,380 |
| PVC floor covering | 1.5 $kg/m^2$ |
| Sand | 1,800 |
| Steel | 7,800 |
| Timber (dry) | 420 |

*Table 5: Material quantities in each building component*

| Building component | Material | Quantity (kg) | |
|---|---|---|---|
| | | Actual NOW Home® design | Alternative NOW Home® design (Alternative 4[23]) |
| Foundation | | 86,696 | 22,315 |
| *Hardfill* | | 34,197 | 6,024 |
| | Polyethylene DPC (NZ) | 33 | 5 |
| | Gravel | 26,280 | 4,812 |
| | Sand | 7,884 | 1,207 |
| *Slab insulation* | | 457 | 0 |
| | Polystyrene | 22 | 0 |
| | Hardiflex flat sheet (NZ) | 435 | 0 |
| *Concrete slab and footings* | | 51,478 | 15,841 |
| | Concrete (NZ) | 51,090 | 15,694 |
| | Timber boxing (NZ) | 355 | 137 |
| | Flashings | 33 | 10 |
| *Reinforcing* | | 564 | 120 |
| | Steel wire (NZ) | 564 | 120 |
| *Timber piles* | | 0 | 329 |
| | Timber (NZ) | 0 | 329 |
| Walls | | 8,907 | 15,807 |
| External walls | | 4,714 | 11,613 |
| *Framing* | | 1,632 | 1,632 |
| | Timber frame (NZ) | 1,608 | 1,608 |
| | Steel bracing | 2 | 2 |
| | Dampcourse bitumac | 22 | 22 |
| *Insulation* | | 116 | 116 |
| | Fibre glass Pink Batts (NZ) | 116 | 116 |
| *External finish* | | 1,777 | 8,676 |
| | Paint (NZ) | 54 | 0 |

[23] *Alternative 4 replaces concrete floor with a suspended timber floor, weatherboard cladding with brick cladding, and concrete tile roofing with steel roofing.*

| Building component | Material | Quantity (kg) | |
|---|---|---|---|
| | | Actual NOW Home® design | Alternative NOW Home® design (Alternative 4[24]) |
| | Weatherboards (NZ) | 1,627 | 0 |
| | Brick (NZ) | 0 | 8,448 |
| | Fibre cement (NZ) | 0 | 208 |
| | Additional trim (NZ) | 42 | 0 |
| | Soakers | 34 | 0 |
| | Building paper | 20 | 20 |
| *Internal finish* | | 1,189 | 1,189 |
| | Gypsum board (NZ) | 1,146 | 1,146 |
| | Finishing timber (NZ) | 16 | 16 |
| | Paint (NZ) | 27 | 27 |
| **Internal walls** | | **4,194** | **4,194** |
| ***Framing*** | | **1,707** | **1,707** |
| | Timber frame (NZ) | 1,705 | 1,705 |
| | Steel bracing | 2 | 2 |
| ***Finish*** | | **2,487** | **2,487** |
| | Gypsum board (NZ) | 2,293 | 2,293 |
| | Tiles (kitchen and bathroom) (NZ) | 116 | 116 |
| | Finishing timber (NZ) | 24 | 24 |
| | Paint (NZ) | 54 | 54 |
| **Floors** | | **130** | **4,034** |
| ***Framing*** | | **0** | **1,779** |
| | Timber (NZ) | 0 | 1,777 |
| | Steel (galv) | 0 | 2 |
| ***Insulation*** | | **0** | **158** |
| | Fibre glass Pink Batts (NZ) | 0 | 158 |
| ***Flooring*** | | **0** | **1,826** |
| | Timber nogging (NZ) | 0 | 611 |
| | Particleboard (NZ) | 0 | 1,215 |
| ***Covering*** | | **130** | **271** |
| | Hydrocoat epoxy sealer | 20 | 0 |

***[24] Alternative 4 replaces concrete floor with a suspended timber floor, weatherboard cladding with brick cladding, and concrete tile roofing with steel roofing.***

| Building component | Material | Quantity (kg) | |
|---|---|---|---|
| | | Actual NOW Home® design | Alternative NOW Home® design (Alternative 4[25]) |
| | Carpet | 81 | 231 |
| | Vinyl | 0 | 11 |
| | Tiles (bathroom) (NZ) | 29 | 29 |
| **Roof** | | **14,415** | **6,370** |
| ***Eaves*** | | **338** | **338** |
| | Hardisoffit flat sheet (NZ) | 290 | 290 |
| | Timber (NZ) | 46 | 46 |
| | PVC | 2 | 2 |
| ***Framing*** | | **2,151** | **2,151** |
| | Timber (NZ) | 2,142 | 2,142 |
| | Steel (galv) | 9 | 9 |
| ***Roofing*** | | **9,511** | **1,465** |
| | Concrete tile (NZ) | 8,858 | 0 |
| | Steel roofing (NZ) | 0 | 1,106 |
| | Building paper | 37 | 37 |
| | Timber battens (NZ) | 616 | 323 |
| ***Ceiling*** | | **1,903** | **1,903** |
| | Paint (NZ) | 35 | 35 |
| | Gypsum board (NZ) | 1,743 | 1,743 |
| | Steel (galv) | 126 | 126 |
| ***Insulation*** | | **320** | **320** |
| | Fibre glass Pink Batts (NZ) | 320 | 320 |
| ***Fascia guttering*** | | **192** | **192** |
| | Colorsteel (NZ) | 192 | 192 |
| **Windows** | | **847** | **847** |
| | Flashings | 9 | 9 |
| | Aluminium frame (NZ) | 183 | 183 |
| | Glass | 596 | 596 |
| | Timber reveal (NZ) | 59 | 59 |
| | Paint (NZ) | 1 | 1 |

*[25] Alternative 4 replaces concrete floor with a suspended timber floor, weatherboard cladding with brick cladding, and concrete tile roofing with steel roofing.*

| Building component | Material | Quantity (kg) | |
|---|---|---|---|
| | | Actual NOW Home® design | Alternative NOW Home® design (Alternative 4[26]) |
| **Doors** | | **366** | **366** |
| ***Interior doors*** | | **302** | **302** |
| | Hollow core timber (NZ) | 245 | 245 |
| | Paint (NZ) | 14 | 14 |
| | Timber (NZ) | 30 | 30 |
| | Copper flashing | 13 | 13 |
| ***Garage door*** | | **64** | **64** |
| | Colorsteel (NZ) | 47 | 47 |
| | Timber (NZ) | 16 | 16 |
| | Paint (NZ) | 1 | 1 |
| **Integrated Water Systems** | | **268** | **268** |
| | Copper tubing | 11 | 11 |
| | Polypropylene | 8 | 8 |
| | Polyethylene rainwater tank | 250 | 250 |
| **Pergola** | | **168** | **168** |
| | Polycarbonate | 7 | 7 |
| | Timber (NZ) | 71 | 71 |
| | Glulam timber | 81 | 81 |
| | Steel (galv) | 8 | 8 |
| **Total** | | **111,797** | **50,173** |

[26] *Alternative 4 replaces concrete floor with a suspended timber floor, weatherboard cladding with brick cladding, and concrete tile roofing with steel roofing.*

*Table 6: Total weight of building components (excluding maintenance)*

| Building elements (kg) | Actual NOW Home® design | Alternative NOW Home® design (Alternative 4) |
|---|---|---|
| Foundations | 86,696 | 22,315 |
| Floors | 130 | 4,034 |
| External walls | 4,714 | 11,613 |
| Internal walls and partitions | 4,194 | 4,194 |
| Ceiling | 2,223 | 2,223 |
| Roof | 14,415 | 4,147 |
| Windows | 847 | 847 |
| Doors | 302 | 302 |
| Integrated Water Systems | 268 | 268 |
| Other | 232 | 232 |
| Total | 111,797 | 50,173 |

*Table 7: Weight of materials installed for maintenance for 50 and 100-year lifetimes*

| Building component | Material | Lifetime (yrs) | Quantity (kg) | | | |
|---|---|---|---|---|---|---|
| | | | Actual NOW® Home® design | | Alternative NOW Home® design (Alternative 4) | |
| | | | 50 years | 100 years | 50 years | 100 years |
| Walls | | | 2,001 | 9,304 | 1,300 | 8,500 |
| External wall | | | 1,138 | 5,208 | 437 | 4,403 |
| *External finish* | | | 706 | 3,154 | 5 | 2,350 |
| | Paint | 8 | 284 | 621 | N/A | N/A |
| | Weatherboards | 40 | 407 | 2,441 | N/A | N/A |
| | Brick | 80 | N/A | N/A | 0 | 2112 |
| | Fibre cement | 50 | N/A | N/A | 0 | 208 |
| | Additional trim | 40 | 10 | 62 | 0 | 0 |
| | Building paper | 40 | 5 | 30 | 5 | 30 |
| *Internal finish* | | | 432 | 2,054 | 432 | 2,054 |
| | Gypsum board | 40 | 287 | 1,719 | 287 | 1,719 |
| | Finishing timber | 40 | 4 | 24 | 4 | 24 |
| | Paint | 8 | 142 | 311 | 142 | 311 |
| Internal wall | | | 863 | 4,097 | 863 | 4,097 |
| *Lining and finish* | | | 863 | 4,097 | 863 | 4,097 |
| | Gypsum board | 40 | 573 | 3,440 | 573 | 3,440 |
| | Finishing timber | 40 | 6 | 36 | 6 | 36 |
| | Paint | 8 | 284 | 621 | 284 | 621 |
| Floors | | | 448 | 997 | 949 | 2,139 |
| | Carpet | 10 | 325 | 731 | 923 | 2,076 |
| | Vinyl | 15 | N/A | N/A | 26 | 64 |
| | Epoxy resin | 7 | 123 | 266 | N/A | N/A |
| Roof | | | 667 | 9,913 | 1,025 | 5,740 |
| *Eaves* | | | 0 | 292 | 0 | 292 |

| Building component | Material | Lifetime (yrs) | Quantity (kg) | | | |
|---|---|---|---|---|---|---|
| | | | Actual NOW® Home® design | | Alternative NOW Home® design (Alternative 4) | |
| | | | 50 years | 100 years | 50 years | 100 years |
| | Hardisoffit flat sheet | 50 | 0 | 290 | 0 | 290 |
| | PVC | 50 | 0 | 2 | 0 | 2 |
| *Roofing* | | | 0 | 6,316 | 357 | 2,143 |
| | Concrete tile | 60 | 0 | 5,905 | N/A | N/A |
| | Steel roofing | | N/A | N/A | 276 | 1,659 |
| | Timber battens | 60 | 0 | 411 | 81 | 484 |
| *Spouting* | | | | | | |
| | Colorsteel | 40 | 48 | 288 | 48 | 288 |
| *Ceiling* | | | 619 | 3,016 | 619 | 3,016 |
| | Paint | 8 | 184 | 403 | 184 | 403 |
| | Gypsum board | 40 | 436 | 2,614 | 436 | 2,614 |
| **Windows** | | | **216** | **1,278** | **216** | **1,278** |
| | Flashing | 40 | 2 | 13 | 2 | 13 |
| | Aluminium frame | 40 | 46 | 274 | 46 | 274 |
| | Glass | 40 | 149 | 894 | 149 | 894 |
| | Timber reveal | 40 | 15 | 88 | 15 | 88 |
| | Paint | 8 | 4 | 9 | 4 | 9 |
| **Doors** | | | **142** | **574** | **142** | **574** |
| | Hollow core timber | 40 | 61 | 368 | 61 | 368 |
| | Paint | 8 | 74 | 161 | 74 | 161 |
| | Timber | 40 | 8 | 46 | 8 | 46 |
| **Integrated Water Systems** | | | **8** | **23** | **8** | **23** |
| | Polypropylene | 25 | 8 | 23 | 8 | 23 |
| **TOTAL** | | | **3,482** | **22,089** | **3,639** | **18,254** |

# 9 References

Anderson, J., Shiers, D. and Steele, K. (2009). *The Green Guide to Product Specification: An Environmental Profiling Systems for Building Materials and Components*. London: BRE Press / Wiley Blackwell.

Frischknecht, R., Jungbluth, N., Althaus, H.J., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G. and Spielmann, M. (2004). ‚The ecoinvent Database: Overview and Methodological Framework' in *International Journal of LCA*, 10 (1), pp.3-9.

Kellenberger, D. and Althaus, H. (2008) 'Relevance of simplifications in LCA of building components' in *Building and Environment*, pp.1–8.

Nebel, B. (2006). *White Paper: Life Cycle Assessment and the Building and Construction Industry*. Report TE200/2 for Beacon Pathway Ltd.

Nebel, B. and Szalay, Z. (2006) *Analysis of Currently Available Environmental Profiles of Building Products*. Report TE200/3 for Beacon Pathway Ltd.

Nebel, B. (2007) *Guideline for LCA Practitioners and Users of Building-related LCA Studies*. Report TE201//2 for Beacon Pathway Ltd.

Nebel, B., Alcorn, A. and Wittstock, B. (2009). *Life Cycle Assessment: Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand*. Rotorua: Scion.

Pollard, A., French, L., Heinrich, M., Jaques, R. and Zhao, J. (2008). *Waitakere NOW Home®: Performance Monitoring: Year Two Report*. Report NO102/4 for Beacon Pathway Limited.

UNEP (2007) *Buildings and Climate Change: Status, Challenges and Opportunities.*

US Department of Energy. *Building America program*. Retrieved 1 February 2010 from http://www1.eere.energy.gov/buildings/building_america/systems_engineering.html