SM3570/8

Life Cycle Assessment of the Waitakere NOW Home®

Final

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About This Report

Title

Life Cycle Assessment of the Waitakere NOW Home®

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Abstract

This report provides an assessment of the environmental impacts of the Waitakere NOW Home® using Life Cycle Assessment (LCA). All life cycle stages from material manufacturing through to the end of life of the house are included. The inputs in the life cycles of the Waitakere NOW Home® were modelled using New Zealand data and international data.
The operational stage of the Waitakere NOW Home® was the most dominant stage in terms of global warming potential, embodied energy, and acidification potential of the life cycle, accounting for between 65-76% of the total impact. The foundation system in the Waitakere NOW Home® accounted for the greatest proportion of the eutrophication and global warming potential of the building. This was largely due to the large mass of concrete which accounted for a high proportion of the mass of both the foundations and the Waitakere NOW Home®. The original NOW Home® design was compared to four alternative NOW Home® designs, and the original NOW Home® had the lowest overall life cycle impact for energy consumption and global warming potential. The difference between the life cycle global warming potential between Auckland and Wellington for all the NOW Home® designs was large and this was due to the operational impact, which increased by 120% (suspended timber floor) to 183% (actual NOW Home®) between the regions.

Reference

Drysdale, D. and Nebel, B. August 2009. Life Cycle Assessment of the Waitakere NOW Home®.Report SM3570/8 for Beacon Pathway Limited.

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1 Executive Summary

This report provides an analysis of the environmental impacts of the Waitakere NOW Home® using Life Cycle Assessment (LCA).

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® (cradle to gate) with the operational energy use during the use phase of 100 years;
- provide a benchmark for the development of further NOW homes ®; and
- compare the life cycle impact of the actual NOW Home® design in Auckland with four alternative NOW Home® designs in two other climate zones.

New Zealand specific life cycle inventory data was available for numerous materials installed in the Waitakere NOW Home®, which accounted for the majority of the mass of the building (just under 70%). However the use of European data, due to the lack of New Zealand specific life cycle inventory data for some building materials, is a limitation of the study. Despite this, the results still provide indicative results that allow a meaningful hot spot analysis.

Environmental hotspots

All environmental impacts are presented in terms of the functional unit; the Waitakere NOW Home® over a 100-year period in New Zealand, providing a home for a family of four.

The operational stage was the most dominant stage in terms of acidification potential, global warming potential and energy consumption. The construction and maintenance stages were the next largest contributors to the life cycle impacts, accounting for similar proportions for each impact category, apart from photochemical ozone creation potential, where the maintenance stage had a greater impact caused largely by reapplication of paint. The foundation system of the Waitakere NOW Home® accounted for the greatest proportion of the eutrophication and global warming potential of the building, which was largely due to the quantity of concrete used. The wall system of the Waitakere NOW Home® (external and internal) accounted for the greatest proportion of the total acidification potential and photochemical ozone creation potential of the building, which was largely due to paint. The global warming potential of all the building systems with built-in timber was lowered due to the stored carbon within the timber.

Embodied versus operational energy

The use phase of the Waitakere NOW Home®, including heating, lighting and hot water provision, was the most dominant stage in terms of global warming potential, embodied energy, and acidification potential of the life cycle, accounting for between 65-76% of the total impact.

Benchmark

This study is a ‘one off’ study that was undertaken retrospectively. The study was based on the assumption that the materials were chosen with regard to their sustainability related performance. To test the sustainability of the materials chosen for the Waitakere NOW Home®, the life cycle impact of both the Waitakere NOW Home® and four alternative NOW Home® designs were compared. It was shown that the Waitakere NOW Home® had the lowest life cycle impact for energy consumption and global warming potential but not acidification eutrophication or photochemical ozone creation potential.

The specific construction and maintenance results for the Waitakere NOW Home® can be used as a benchmark for future homes, but cannot provide an answer to the absolute performance with regard to the environmental impacts.

2 Introduction

2.1 Background

Beacon Pathway Limited is a research consortium that aims to enhance the sustainability of New Zealand households and neighbourhoods. Beacon's vision is to 'create homes and neighbourhoods that work well into the future without costing the earth'. This vision is guided by two goals:

1) To bring 90% of New Zealand homes to a high standard of sustainability by 2012.
2) Every new subdivision and any redeveloped subdivision or neighbourhood will be developed from 2008 onwards with reference to a nationally recognised sustainability framework.

Beacon's research on homes has two strands: retrofit and new build. A major foundation of this research involves the NOW Home® programme, whereby Beacon has designed and built two demonstration sustainable homes, which are being lived in and monitored. Some existing homes are also being retrofitted as part of this programme. These homes are 'live' research projects that aim to show that sustainable, affordable and desirable homes can be built now using available design concepts, materials and products.

Beacon's Waitakere NOW Home® project aimed to point the way for future housing design and construction by using materials and technology readily available now.

One way of analysing and evaluating the sustainability and environmental performance of the Waitakere NOW Home® is by using Life Cycle Assessment (LCA). The LCA methodology takes a systems perspective over the whole life cycle of a building, and thus avoids problem-shifting from one life cycle stage to another, from one geographical area to another and from one environmental medium to another.

In this study, the Waitakere NOW Home® was analysed using LCA in order to:

- provide insight into the environmental hot spots of the Waitakere NOW Home®;
- compare the embodied energy of the home to the operational energy of the home;
- assist with the identification of the systems that contribute most strongly to the environmental impacts of a home in order to prioritise systems for further research;
- provide a benchmark for the development of further NOW homes ®; and
- compare the life cycle impact of the actual NOW Home® design in Auckland with four alternative NOW Home® designs in two other climate zones.

As well as addressing the above criteria, this report also describes the methodology, underlying data and assumptions used in the LCA of the Waitakere NOW Home®.

2.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is based on the concept of integrating consumption and production strategies over the whole life cycle. LCA is an analytical tool for the systematic evaluation of the environmental impacts of a product or service through all stages of its life. It extends from extraction and processing of raw materials through to manufacture, delivery, use and finally on to waste management. This is often referred to as “cradle to grave”. A number of other environmental assessment tools are restricted to the production process (sometimes called “gate to gate” or, in the case of embodied energy, cover the extraction of the raw materials through to completed production, sometimes called “cradle to gate”) without taking the end of life into account (Baumann & Tillman, 2002).

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. LCA can also identify hot spots in upstream and downstream processes, such as the type of energy used in the construction and use of the building and the production of materials used in the building.

See Appendix 5 for an overview of the methodology.

2.3 Structure of this Report

This report is divided into the four phases of LCA; *Goal and Scope Definition, Inventory Analysis, Impact Assessment,* and *Interpretation.* The summary and conclusions gained from the study are presented at the end of the report.

3 Waitakere NOW Home®

The Waitakere NOW Home® is a research experiment designed to test how an innovative design and construction concept delivers nine fundamental objectives of a sustainable home (Bayne et al., 2005).

The Waitakere NOW Home® was designed and built on the principles of maximising the sun's warmth, reducing water use and providing a dry, healthy indoor environment. It was designed with the 'average' New Zealander in mind, and to be within reach of the median household income, while recognising that significant savings are needed to reach the 10-20% deposit generally required for a mortgage. Overall the NOW Home® aimed to balance environmental, social and economic gains. The characteristics of the Waitakere NOW Home® are as follows (Trotman, 2008):

- a single storey, three bedroom home of 146 m^2 (including the garage);
- built at a cost of $213,853 + GST, excluding landscaping and soft furnishings;
- designed to be affordable to most New Zealanders;
- designed for a hypothetical, average, young New Zealand family;
- 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; and
- built from materials chosen for integrity and durability to maintain capital value and ensure weathertightness.

3.1 Goal and Scope Definition

3.1.1 Goal

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® (cradle to gate) with the operational energy use during the use phase;
- provide a benchmark for the development of further NOW homes ®; and
- compare the life cycle impact of the actual NOW Home® design with four alternative NOW Home® designs in two other climate zones.

3.1.2 Scope and System Boundaries

The analysis took into account the life cycle phases of construction, use, maintenance, transportation of materials to site and end of life. Construction includes the manufacturing and transport of the raw materials and products, and site preparation. The system boundary of the study is shown in Figure 1.

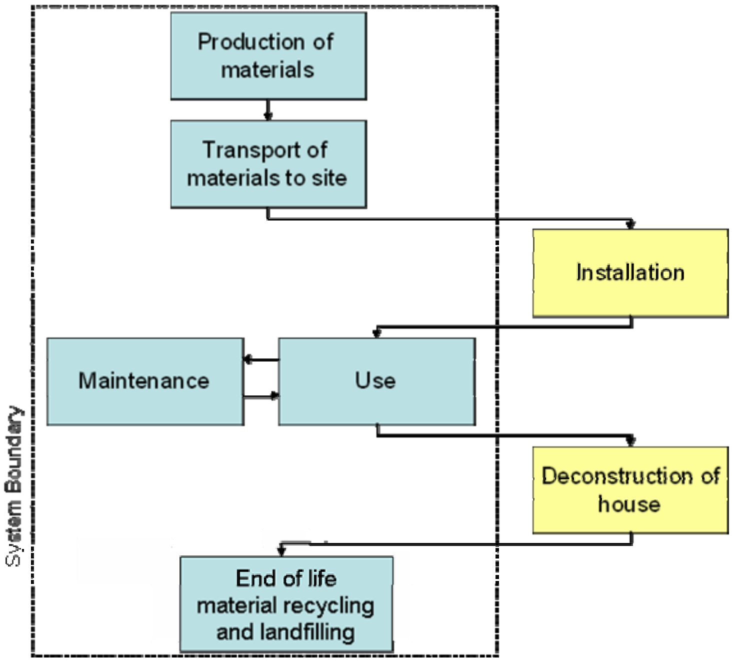

Figure 1: LCA system boundary for the Waitakere NOW Home®

The provision of infrastructure and capital goods, such as roads, trucks for transport, machinery etc., was not considered as the impacts are negligible (Frischknecht et al., 2007). Accidents and misuse, including the vandalism and mistakes that occurred during construction, were excluded from the analysis.

Waste materials caused by damages, cut-offs etc., have been included in the study. Other waste material such as packaging has been excluded from the analysis, as the environmental impact from these materials is assumed to be negligible compared with other materials analysed.

The impacts associated with the construction and deconstruction of the Waitakere NOW Home® were excluded from the analysis because the contribution to the overall life cycle impact is minimal (Kellenberger & Althaus, 2008).

Maintenance has been included in the study in two scenarios; for useful life times of the house for 100 years and for 50 years. One hundred years was chosen because it is the average lifetime of a house built in New Zealand (Johnson, 1994), and 50 years was chosen because it is the minimum lifetime set by the Building Code (Building Act, 2004). The Waitakere NOW Home® in the 100-year scenario requires more maintenance than in the 50-year scenario. All other life cycle stages (i.e. production of materials, disposal etc.) are identical for both scenarios.

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.

Utilities such as hand basins, toilets, kitchen sink etc. were excluded from the system boundaries because these are not part of the structural systems of the Waitakere NOW Home®. However, the rainwater tank was included as part of the integrated water system in the assessment.

Site preparation (excavation) as well as the boxing around the concrete slab has been included in the study. Landscaping (as opposed to site preparation) was excluded because it is not influenced by the building design itself.

3.1.3 Functional Unit

The functional unit is the Waitakere NOW Home® itself over a 100-year/50-year period in New Zealand, as a home for a family of four. Heating, lighting and the provision of hot water were included. All results will be presented in terms of this functional unit.

3.1.4 Data Quality

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

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

Input – output data

A comprehensive list of all material quantities was unavailable for the Waitakere NOW Home® and the alternative NOW Home® designs, which meant some material quantities had to be calculated. Material quantities were calculated for the following building systems: floor/foundations (concrete slab and suspended timber floor), walls (timber weatherboard cladding and brick cladding), doors, windows, ceiling and roof (concrete roofing tiles and steel roof), garage door, pergola and integrated water systems.

The majority of information regarding materials installed in the Waitakere NOW Home® was available from invoices for work done. However, detailed information regarding the mass of each material was variable. The invoices provided a varying degree of data quality ranging from: material dimensions and quantity purchased through to only labour costs.

Waitakere NOW Home®

Material quantities have been calculated for the Waitakere NOW Home® based on documents provided and personal communications with stakeholders. All efforts to determine accurate material quantities were made. A quality check was carried out between Waitakere NOW Home® material estimations and material quantities supplied in an LCA study of a two storey

Exemplar house of similar materials and quantities (Szalay & Nebel, 2006). The quality check ensured material quantities were as accurate as possible.

Alternative NOW Home® designs

The building systems within the alternative NOW Home® designs were also modelled in the Exemplar study. Therefore a quality check was also carried out between the material quantity estimations for the alternative building system designs and the material quantities supplied in the Exemplar study (Szalay & Nebel, 2006). The quality check ensured material quantities were as accurate as possible.

Life cycle inventory data

New Zealand specific life cycle inventory data was used for numerous building materials. These materials are indicated with "(NZ)" in Table 15.

New Zealand specific data for the remaining materials in Table 15 is currently unavailable. The life cycle inventory data used for these materials is based on European industry data (GaBi, 2006). The data has been amended and checked for consistency with literature data and is compliant with the ISO Standards 14040 and 14044. The documentation of the data describes the production process, applied boundary conditions, allocation rules etc. for each product. The data covers resource extraction, transport, and processing i.e. "cradle to gate". Included are material inputs, energy inputs, transport, outputs as well as the emissions related to energy use and production. Capital equipment is excluded[1].

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. The life cycle impact involves production, use, and disposal. It has been shown, for the production stage of treated timber, that the contribution of treatment chemicals to the overall energy consumption and global warming potential of treated timber is minimal (<5%) (Vial et al. 2009).

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

3.2 Inventory Analysis

The inventory analysis provides detailed material and energy balances over the life cycle identified in the Goal and Scope Definition. All quantities of material and energy inputs, and product and emission outputs to air, water and land are compiled into one inventory, which was then used as an input into the life cycle impact assessment. The inventory is structured according to the life cycle stages of the Waitakere NOW Home®; construction (including upstream production of materials), maintenance, transport, use and disposal at end of life.

3.2.1 System Definition

Systems are defined as the smallest part of a "building" where function (functional unit) can be appropriately prescribed. The function can be one or several relevant properties e.g. static properties, heat and sound transfer or insulation (Bayne et al., 2008).

The systems within the Waitakere NOW Home® have been designed specifically for purpose, location, orientation and budget. The building aims to be highly efficient in terms of water and energy, as well as being built from materials and technologies that are available *now*, therefore each building system has been designed in order to achieve this.

The seven main systems that were analysed in this study are defined below, along with the components within each system.

1) *Floor/foundations*
   - Hardfill
   - Concrete slab and footings (includes timber boxing)
   - Concrete slab insulation
   - Flooring materials (includes hydrocoat epoxy sealer, carpet and ceramic tiles)

2) *External walls (part of building envelope)*
   - Exterior finish (i.e. timber weatherboard cladding, paint etc.)
   - Framing
   - Interior finish (i.e. internal gypsum board lining, skirting, paint etc.)
   - Insulation

3) *Internal walls and partitions*
   - Framing
   - Finish (i.e. gypsum board lining, skirting, paint etc.)

4) *Ceiling and roof*
   - Ceiling (i.e. gypsum board lining, steel nail up battens, paint etc.)
   - Insulation
   - Framing
   - Roofing (i.e. concrete tiles, battens etc.)
   - Eaves (i.e. fibrecement soffits, PVC joiners etc.)

- Fascia guttering (assumed main function is fascia)

5) *Windows (includes aluminium framed glazed doors)*
   - Aluminium framing
   - Glass
   - Finish (i.e. timber, paint etc.)

6) *Doors*
   - Internal wooden doors (including wardrobe doors)
   - Wooden front door

7) *Integrated Water Systems*
   - Polypropylene downpipes
   - Polyethylene rainwater tank
   - Internal plumbing

Other components
- Garage door
- Pergola

3.2.2 Alternative NOW Home® Systems

Four alternative building systems within the NOW Home® were assessed in this study. These systems are presented below and they replaced the original respective systems presented above. For example, suspended timber floor replaced concrete slab and the remaining building systems in the NOW Home® remain the same. 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®.

1) *Floor/foundations*
   - Hardfill (under garage concrete slab only)
   - Suspended timber floor (including all the relevant timber components, e.g. piles, joists etc.) and garage concrete slab (includes timber boxing)
   - Underfloor insulation
   - Flooring materials (includes vinyl, carpet and tiles)

2) *External walls (part of building envelope)*
   - Exterior finish (i.e. brick cladding etc.)
   - Framing
   - Interior finish (i.e. internal gypsum board lining, skirting etc.)
   - Insulation

3) *Ceiling and roof*
   - Ceiling (i.e. gypsum board lining, steel nail up battens etc.)
   - Insulation

- Framing
- Roofing (i.e. steel roofing, battens etc.)
- Eaves (i.e. hardisoffit, PVC joiners etc.)
- Fascia guttering (assumed main function is fascia)

3.2.3 Data Collection

Various methods were employed to determine the mass of materials within the Waitakere NOW Home®. Information provided by the invoices was presented as either: cubic metres, square meters, length, number purchased, labour cost.

Where volumetric amounts were provided, the mass was determined by multiplying the volume by the standard density of the material. This included, for example, concrete, timber and expanded polystyrene (EPS). In most cases the dimensions (width, length and thickness) of the timber products were provided, and the total volume was calculated from this information.

Two volumes were provided for the concrete slab: original estimates and actual poured volume. The reason for this was that during excavation three tree stumps were uncovered and removed. This resulted in an increased amount of concrete required to fill the holes left by the stumps. This situation was deemed highly rare and unfortunate, therefore, in order to develop a more realistic quantity of concrete, the original volumetric estimates were used as the basis for mass calculation.

Where data on the area of a material was provided, the thickness of that material was obtained from the company where the material was purchased, or the thickness was assumed. Tiles installed in the kitchen and bathroom are an example of this, with the company supplying information.

In cases where no information was provided, various methods as described below were employed to estimate the material quantity in the building.

Information was unavailable for the quantity of roofing tiles, therefore the building plans were utilised. The total roof area was calculated based on dimensions and sketches provided in the building plans. Number of tiles and mass per metre squared were provided by Rosscrete who installed the roof. The length of timber battens installed under the roofing tiles was also estimated using the building plans.

The quantity of aluminium installed in the windows was calculated by multiplying the total perimeter of all windows by the weight per metre length (1.28 kg/m) of window frame, which was provided by BRANZ[2].

Where it was known that a material was installed in the Waitakere NOW Home® but dimensional and quantitative information was unavailable, then the surface area which the material covered was used. Examples include paint, carpet and glass wool. Two steps were carried out to determine the mass of material. Step one was to calculate the volume by

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[2] ***R. Jaques, BRANZ, Personal Communication, 25th June, 2008***

multiplying thickness of material by the metre squared coverage. Step two was to multiply material density by metre cubed. Mass of carpet was calculated based on a kg/m^2 density.

Once the volume of each material was determined, the total mass was calculated by multiplying the volume by the material density. All densities used in this study are presented in Table 14. Densities have been taken from Szalay and Nebel (2006) as well as industry information, provided either by company websites or through personal communications with company staff.

For the alternative building systems (suspended timber floor, brick cladding, and steel roofing), the materials in each of the different systems were determined following similar methods as detailed above. Each of these building systems was also modelled in the Exemplar study (Szalay and Nebel, 2006) and subsequently the material quantities for each system was supplied. A quality check could therefore be carried out between both the material quantities developed for this study and the Exemplar study.

3.2.4 Material Quantities

A breakdown of material quantities in each building system (for the Waitakere NOW Home® and alternative NOW Home® design) is presented in Table 15. Figure 2 presents the percentage contribution, by weight of each system in the Waitakere NOW Home®. The foundation system has the greatest contribution to total mass (78%). The roof (13%), external wall (4%) and internal wall (4%) systems are the next biggest contributors, predominantly due to the concrete roofing tiles and the large quantities of built-in timber in the walls. The ceiling and window system contributed 2% and 1% to total weight respectively, mainly from aluminium window frames and a large mass of glass due to double glazing in the windows, and gypsum board in the ceiling. Table 16 presents the total weight of each building system in both the Waitakere NOW Home® and alternative NOW Home® designs.

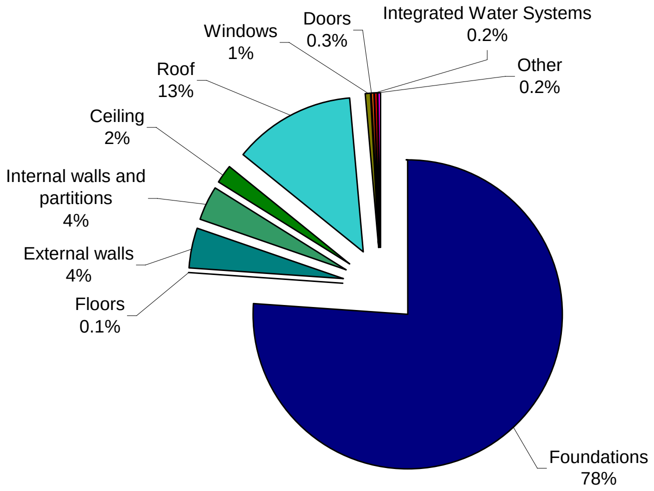

Figure 2: Percentage contribution, by weight of building systems in the Waitakere NOW Home®

Figure 3 presents the percentage contribution, by weight of materials in the Waitakere NOW Home®. Note that only the materials contributing 1% or more have been labelled.

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. Glass, fibre cement and steel contribute around 1% to total mass. All other materials contribute less than 1% and therefore have not been labelled in Figure 3.

Table 17 presents the total weights for all materials in both the Waitakere NOW Home® and the alternative NOW Home®.

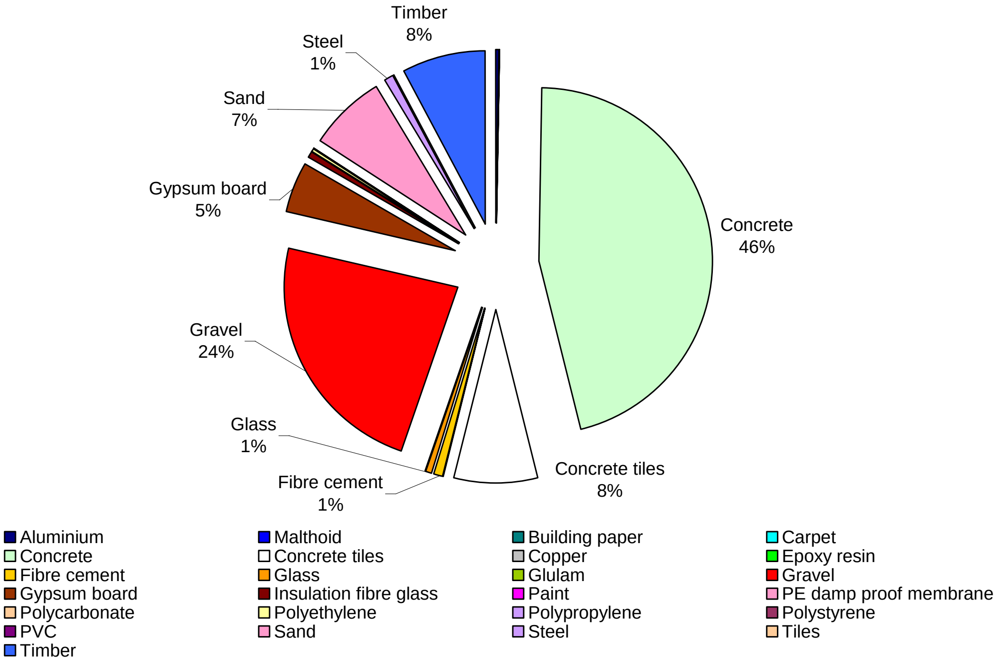

Figure 3: Percentage contribution, by weight of materials installed in the Waitakere NOW Home® (only materials contributing 1% or more have been labelled)

3.2.5 Material Waste

A material waste monitoring project was carried out to determine quantities of all waste generated on the Waitakere NOW Home® site during construction (Kane et al., 2005). The project also identified the amount of material that could be either reused on-site or be otherwise diverted from landfill.

The construction of the Waitakere NOW Home® generated 2,448kg of material wastes. Of this 189kg (8%) of waste materials were diverted from landfill. Materials diverted from land- fill included: untreated timber (used as fuel-wood); polystyrene insulation (delivered to recycling company); #1 and #2 plastics, aluminium cans (recycled using a local kerbside recycling scheme); and clear plastic wrap (also recycled). Table 1 presents the weights of waste materials generated. There is a discrepancy in figures between total weight of materials and total final weight due to the moisture content[3].

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[3] *R. Jaques, BRANZ, Personal Communication, 6th May, 2008*

Table 1: Final weight of waste materials generated through construction of the Waitakere NOW Home®

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

These waste materials have been incorporated in calculations of material quantities. The majority of material masses in the Waitakere NOW Home® were calculated by extracting information from invoices. Naturally, a proportion of materials listed in the invoices would have been discarded as waste (for example timber). No distinction between built-in materials and waste materials was made when determining the mass of each material in the Waitakere NOW Home®.

This does not alter the results because ultimately all materials are sent to landfill at the end of the building's life. This is possible because 92% of waste is sent to landfill, and 8% of waste materials were recycled. However, this equates to only 0.2% of the overall weight of the building. The impact reduction from recycling the materials in comparison to the overall impact would be insignificant thus recycling has been excluded from the assessment.

3.2.6 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 (2006) 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.

3.2.7 Maintenance

Maintenance activities including everyday measures, like repairs or decorating as well as heavy maintenance, like restoration or replacement of building elements and service 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, in order to identify the variation in impact for different building lifetimes. Only the base scenario lifetime of 100 years was modelled for the alternative NOW Home® designs.

Calculations of the number of replacements in the life cycle were prorated. For example, a component with a 20-year life is prorated in a building with a service life of 50 years, the component is replaced 50/20 – 1 = 1.5 times. Prorating reflects the average situation and the uncertainties in lifespans and replacement cycles.

Based on 100 and 50-year lifetimes, a maintenance schedule was developed for the Waitakere NOW Home® and the alternative NOW Home® design, using material lifetimes obtained from Szalay and Nebel (2006).

Table 19 presents the estimated useful lifetimes of materials in the Waitakere NOW Home® based on literature, and the median of these is what was used for the lifetime of each building material.

Material quantities required to maintain the Waitakere NOW Home® and the alternative NOW Home® design during a 100 and 50-year lifetime are presented in Table 18.

It was assumed that identical materials would be used to replace the initial materials in the homes. It was assumed that fibre cement in the eaves would have the same lifetime as fibre cement in external walls i.e. 50 years. It was also assumed polypropylene downpipes would have the same lifespan as the PVC downpipes i.e. 25 years. The polyethylene rainwater tank was not included in the maintenance schedule.

3.2.8 Use Phase

The reticulated energy consumption of the Waitakere NOW Home® was monitored for years one and two (Pollard et al., 2008) and is presented in Table 2. This table presents the total annual reticulated energy use of the Waitakere NOW Home®, which includes all energy end-uses i.e. lighting, cooking and appliances etc. However, this study will assess only energy consumed from heating, lighting and hot-water (HL+HW). These end-uses are seen as intrinsically related to the design of the Waitakere NOW Home®, whereas energy use from appliances, such as the stove for cooking and television for entertainment, are behaviour related and are not directly related to the design of the house, and are thus disregarded[4].

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[4] ***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 dependant on the design of the building and the building envelope.***

The total annual reticulated energy consumption of the Waitakere NOW Home® for year one and year two was 7,400 kWh and 8,500 kWh respectively, and the HL+HW component accounted for 30% and 35% of the total energy consumption for year one and year two respectively.

Table 2: Waitakere NOW Home® annual reticulated energy use for years 1 and 2 and weighted average for both years

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

In order to calculate the lifetime operational energy consumption for HL+HW for 100 and 50 years, an average value for annual energy consumption was calculated. It was assumed that the second year data was more representative of future energy consumption. It was felt that in the second year of occupation the family became more accustomed to their living situation and were more imprudent in regards to their power usage. Therefore the average was calculated by assuming the energy consumption of a third year of operation would be the same as the second year value, and the total operational energy consumption of the three years was divided by three.

The weighted average was upscaled to represent the lifetime operational energy consumption of the Waitakere NOW Home® for 100 and 50 years (Table 2). It was assumed that energy consumption would remain at the same level during the course of the building's life.

Alternative NOW Home® designs

Operational energy data for the alternative NOW Home® designs were calculated using the Annual Loss Factor tool (ALF) developed by BRANZ. Note that only the *heating* energy demand was calculated for these NOW Home® designs, as opposed to the heating, lighting and hot water energy consumption, which was used for the analysis of the initial NOW Home®. The heating energy demand reflected the amount of energy required to reach and sustain the living space temperature at 18^{o}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®.

Note that the main focus of the ALF results was not on the absolute heating energy demand value calculated for each NOW Home® design and climate zone. The focus was on the *difference* between each heating energy demand value of each NOW Home® design in each climate zone.

3.2.9 End of Life

Szalay and Nebel (2006) showed that impacts from the end of life component are minimal in the context of the total life cycle impact. 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 and processing of waste materials in landfill. An average travel distance of 50km was assumed for transporting waste to landfill. An initial sensitivity analysis showed that the impact from transportation of waste to landfill is small and negligible

The initial embodied impact of aluminium window framing is generally high and recycling is a viable option for the material. Therefore it was assumed the aluminium window framing would be recycled at the end of life stage. The benefits from recycling the aluminium were considered when it was installed in the building, as opposed to the end of life stage when the aluminium is actually recycled. This reflects the true embodied impact of the aluminium in the building. The benefit from recycling aluminium is from providing recycled aluminium for further use elsewhere, and avoiding the need for using virgin aluminium, which has a much greater embodied impact. This impact is then deducted from the initial embodied impact of the aluminium. A list of total impact savings for recycling one kilogram of aluminium is presented in Table 3.

Table 3: Impact mitigation, for each impact category, from recycling one kilogram of aluminium (PE International, 2006)

Impact category	Impact saving	Unit
Acidification potential	-0.04	kg SO2-Equiv.
Eutrophication potential	-0.002	kg Phosphate-Equiv.
Global warming potential	-8.8	kg CO2-Equiv.
Photochemcial ozone creation potential	-0.004	kg Ethene-Equiv.
Energy consumption	-134	MJ

Concrete roofing tiles and timber weatherboards were assumed to be landfilled based on a lack of information. In theory these materials could be reused / recycled.

The total mass of materials in the Waitakere NOW Home® that was sent to landfill was 133,885kg (100 yrs) and 115,278kg (50 yrs). This included all materials from: initial construction, waste and maintenance. Energy related to the deconstruction of the building was excluded from end of life assessment, however transport of materials to landfill and processing was included.

Carbon storage in landfill

When kiln-dried timber (≈ 12% moisture content dry basis) is sent to landfill, a proportion of the timber decomposes releasing GHG emissions, and a proportion remains permanently buried in landfill. For every kilogram of kiln-dried timber sent to landfill, 0.924kg CO_2 equivalents will be released into the atmosphere, and 1.65kg CO_2 will be stored permanently (Nebel & Drysdale, 2009). These figures have been calculated based on the most up-to-date literature concerning: timber decomposition rates in landfill; GHG emission ratios (CO_2 versus CH_4), methane oxidisation rates from soil microbes and landfill methane capture rates (Ximenes et al. 2008, Micales and Skog 1997, IPCC 2006).

In New Zealand 42% of the methane released from decomposition of timber in landfill is captured (MfE, 2009). Though it is probable that methane capture rates differ between landfills in different regions, this capture rate was not altered for this study, and specific methane capture rates of individual landfills were not considered.

The stored carbon in the timber in landfill has been deducted from the embodied impact of the timber installed in the building. The net embodied global warming potential of timber installed in construction and maintenance, reflects the GHG emissions from both the production of the timber and decomposition of the timber in landfill, minus the carbon that is permanently stored in the timber in landfill (Figure 4).

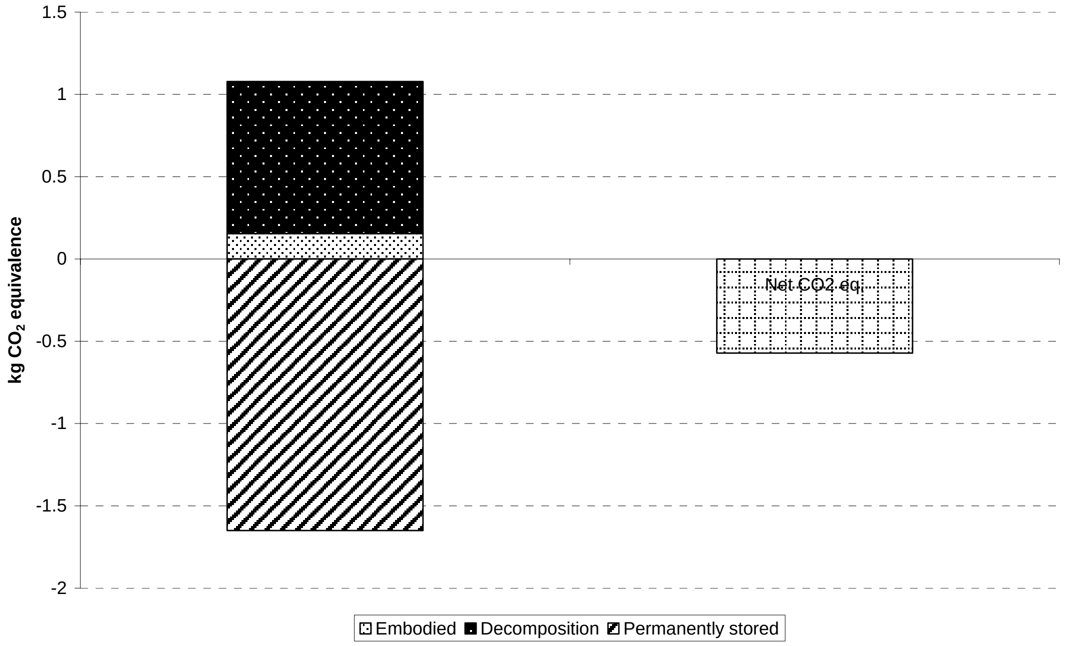

Figure 4: Amount of CO_2 equivalents embodied in one kilogram of kiln-dried timber, released through decomposition of timber in landfill, permanently stored in landfill, and net CO_2 equivalents

The timber framing and weatherboards in the Waitakere NOW Home® are treated with boron and Light Organic Solvent Preservative (LOSP), respectively. When the timber is sent to landfill the chemicals within these treatments are also sent to landfill. It has been shown that over a certain period of time (<100 years) the leaching of treatment chemicals from timber in landfill is minimal at <1% (Hauschild et al. 2008; Gifford et al. 1998). This information is based on the assumption that the landfills remain undisturbed within the 100 years. Only when the landfill is disturbed, e.g. by cracking, will the chemicals become re-mobilised. The long term impact from these chemicals (100-10,000 years), which will most likely be related to toxicity, was not considered in this study.

3.3 Impact Assessment

The environmental impacts of the Waitakere NOW Home® life cycle were assessed using CML2001 baseline methodologies (Guinée, 2002). The CML2001 baseline methodologies allow for analysis of environmental impacts in a number of different impact categories. The impact categories assessed in this study are the following:

- global warming (GWP);
- acidification (AP);
- eutrophication (EP); and
- photo-oxidant formation (POCP).

In addition to the above environmental impacts, primary energy was also assessed.

The environmental impacts have been chosen based on a standard for the development of environmental product declarations for building materials (CEN TC 350) and are standard in LCA studies. The “standard” also requires information on the ozone depletion potential. In this study the ozone depletion potential of the materials identified has not been considered. Following the banning of ozone depleting chemicals in the 1987 Montreal Protocol, the atmospheric concentrations of the most important chlorofluorocarbons and related chlorinated hydrocarbons have either levelled off or decreased, but the impacts of past emissions on the ozone layer will still be seen for decades to come. Some identified chemicals, while still in use in products, will not be used in new products (at least to an extent that is likely to be of concern).

3.3.1 Environmental Impacts of Life Cycle Stages

Table 4and Figure 5 present the contribution to each environmental impact of each stage of the life of the Waitakere NOW Home®. The life cycle has been split into four stages; construction, maintenance, operation, 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. Note that impacts from transport are incorporated in the total construction impact.
- *Maintenance* accounts for the embodied impacts of the materials required to maintain the building throughout its lifetime, along with the transport of those materials to the building site. Note that impacts from transport are incorporated in the total maintenance impact.
- *Operation* accounts for the total primary energy consumption of the Waitakere NOW Home® for HL+HW end-uses, during its 100 or 50-year lifetime.
- *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.

Note that the lifetime of the Waitakere NOW Home® in the base scenario was 100 years; however, a sensitivity analysis was conducted which assessed the relative impact from a lifetime of 50 years. The results from this assessment are presented in section 3.3.4.

Table 4: Life cycle environmental impacts of the Waitakere NOW Home®

	AP	**EP**	**GWP**	**POCP**	**Energy [MJ]**
Waitakere NOW Home®	**[kg SO2-Equiv.]**	**[kg Phosphate-Equiv.]**	**[kg CO2-Equiv.]**	**[kg Ethene-Equiv.]**	
Construction	74	9.0	10,980	12	234,106
Maintenance	119	6.1	14,869	41	314,219
Operation	386	12	72,688	12	1,873,724
End of life	14	2.0	3,043	2.0	27,950
Total	593	30	101,581	67	2,424,909

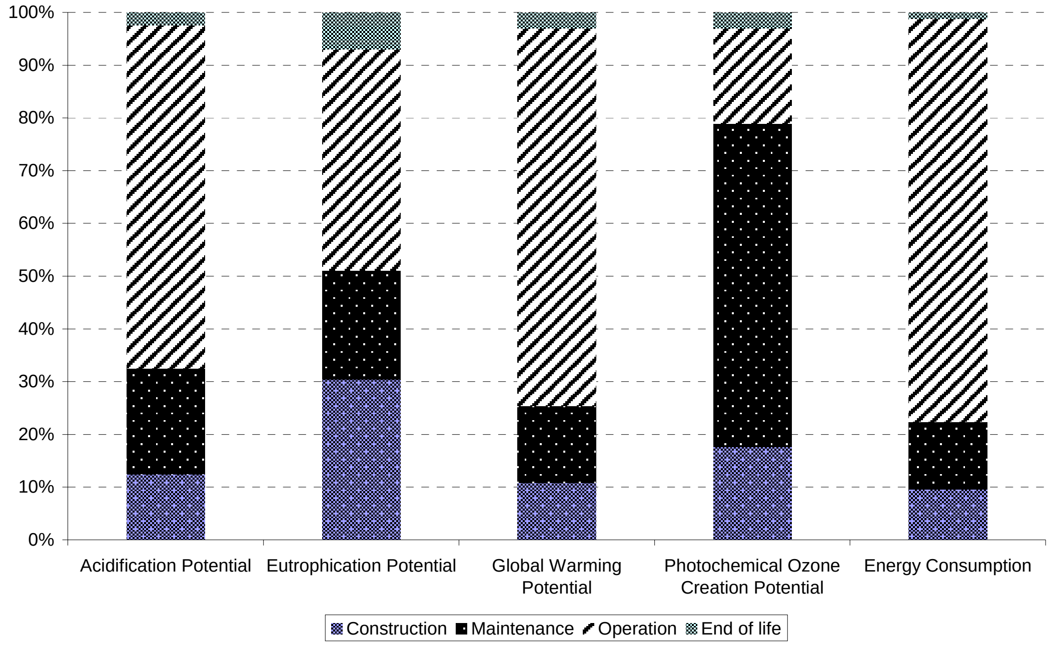

Figure 5: Percentage contribution to environmental impacts of each life cycle stage of the Waitakere NOW Home®

The operational phase contributes the greatest impact for acidification potential, global warming potential and energy consumption, at around 65-76%. However the operational impact for eutrophication potential and photochemical ozone creation potential was only 42% and 18%, respectively.

The construction and maintenance stages were the next largest contributors, both having similar contributions to the life cycle impact of each category, except for eutrophication potential and photochemical ozone creation potential. The construction stage accounted for 30% of the life cycle eutrophication potential and the maintenance stage accounted for 61% of the life cycle photochemical ozone creation potential.

The end of life stage had the smallest contribution to the overall life cycle impact for each impact category.

The construction stage includes the transport of materials to the site which contributes around 3% to the total construction impact for each category, but only 0.5% to the total life cycle impact for each impact category. The contribution of transport to the total maintenance related impact was similar to the contribution of transport to the construction impact as shown above.

Further analysis of the embodied impact of systems and materials in the construction and maintenance stages are presented in section 3.3.2.

3.3.2 Environmental Impacts of Building Systems

This section presents the percentage contribution to each impact category of the building systems assessed in this study. The building systems that account for high percentage contributions are analysed further in section 3.3.3.

Table 5 and Figure 6 present the contribution to each impact category of the building systems analysed in the Waitakere NOW Home®. The main contributors include foundations, external and internal walls, ceiling, roof, windows and the integrated water system.

Table 5: Environmental impacts of each building system in the Waitakere NOW Home® and other components

Waitakere NOW Home® system	**AP**	**EP**	**GWP**	**POCP**	**Energy [MJ]**
	[kg SO2-Equiv.]	**[kg Phosphate-Equiv.]**	**[kg CO2-Equiv.]**	**[kg Ethene-Equiv.]**	
Foundation	14	2.1	5,825	1.3	50,455
Floors	1.2	0.2	576	0.2	10,731
External walls	11	1.0	-1,056	2.4	25,526
Internal walls	7.3	0.7	-115	1.5	20,446
Ceiling	5.0	0.4	1,287	1.1	21,828
Roof	13	1.5	1,414	1.4	43,400
Windows	5.7	0.6	1,237	0.5	16,970
Doors	1.3	0.09	-71	0.3	2,345
Integrated water systems	3.5	0.4	604	1.7	19,910
Other components	0.8	0.1	78	0.1	5,446

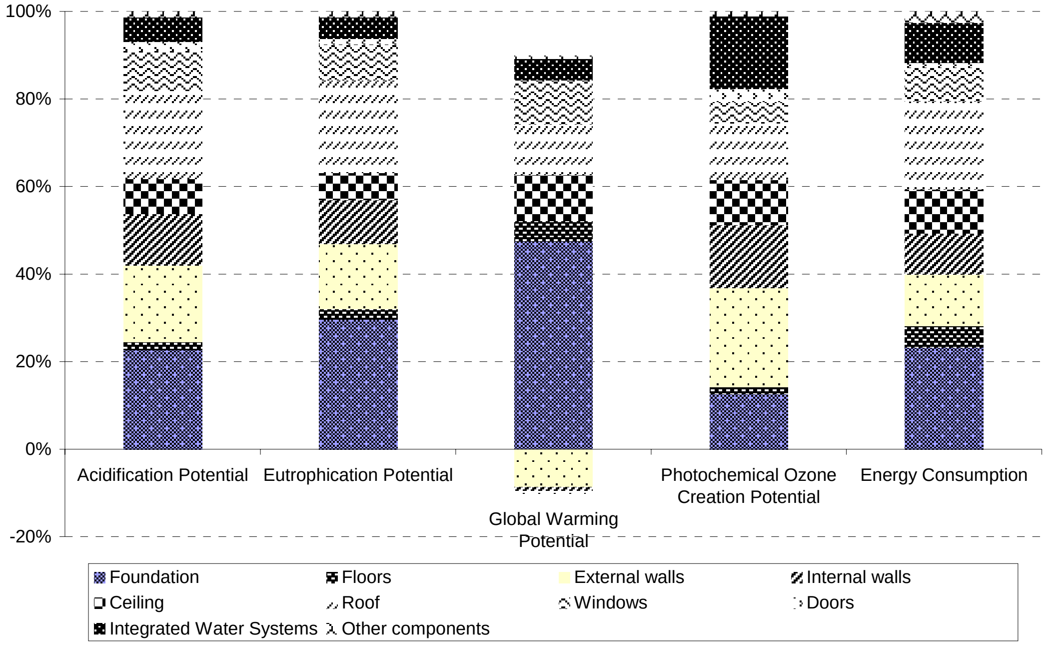

Figure 6: Percentage contribution to environmental impacts of each building system in the Waitakere NOW Home®

The systems with a large amount of built-in wood, such as the external and internal walls and doors, had a net negative global warming potential. This is due to the permanent storage of carbon within the wood when it is landfilled. 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.

The foundation system accounted for the single greatest contribution to the total eutrophication and global warming potential of the building systems, with 30% and 53%, respectively.

The wall system (external and internal) was the main contributor for photochemical ozone creation potential of the building systems, accounting for 37% of the impact. However the external walls accounted for around 61% of this 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.

The "other" building components category in this section include the pergola and garage door which accounted for a minimal proportion of the overall impact of the building at around 1% for each impact category.

Further discussion of each system is presented in section 3.3.3, with identification of the materials that have significant contribution to the embodied impacts of systems.

3.3.3 Hot spot Analysis of Systems

This section highlights the systems and materials that account for a significant contribution to the construction impact of the Waitakere NOW Home®. The systems and materials are assessed in terms of their contribution to the total construction, or system related impact, or on an impact per mass basis. The assessment of the maintenance related impacts in the 50 and 100-year lifetime scenarios will also be discussed in this section.

The analysis will identify:

- the materials that cause a high proportion of impact in each system;
- the materials that cause a high proportion of impact in the Waitakere NOW Home®.

The systems with a high construction impact which are analysed in this section include:

- Foundations
- External walls
- Internal walls
- Windows
- Ceiling
- Roof

The floor system accounted for around 5% of the construction energy consumption, however this was largely due to the carpet (over 70%). The integrated water system accounted for around 9% of the embodied energy of the construction phase, making it a relatively significant contributor; however, a hot spot analysis was not required because this was largely due to the rainwater tank. This system is discussed in the “other” systems or components part of this section which also includes the doors, garage door and pergola.

Foundations

Table 6 and Figure 7 present the contribution to each impact category of the materials installed in the foundation system of the Waitakere NOW Home®.

Table 6: Environmental impacts of each material in the Waitakere NOW Home® foundation system

Foundation material	**AP [kg SO_2-Equiv.]**	**EP [kg Phosphate-Equiv.]**	**GWP [kg CO_2-Equiv.]**	**POCP [kg Ethene-Equiv.]**	**Energy [MJ]**
Gravel	0.3	0.04	55	0.03	859
Sand	0.09	0.01	17	0.01	258
Polyethylene film	0.2	0.02	78	0.05	2,833
Polystyrene	0.1	0.01	57	0.02	1,751
Fibre cement	1.1	0.08	304	0.06	5,945
Steel	0.8	0.0	285	0.1	4,806
Timber	0.6	0.1	-205	0.08	986
Concrete	11	1.8	5234	0.9	33,018
Total	14	2.1	5825	1.3	50,455

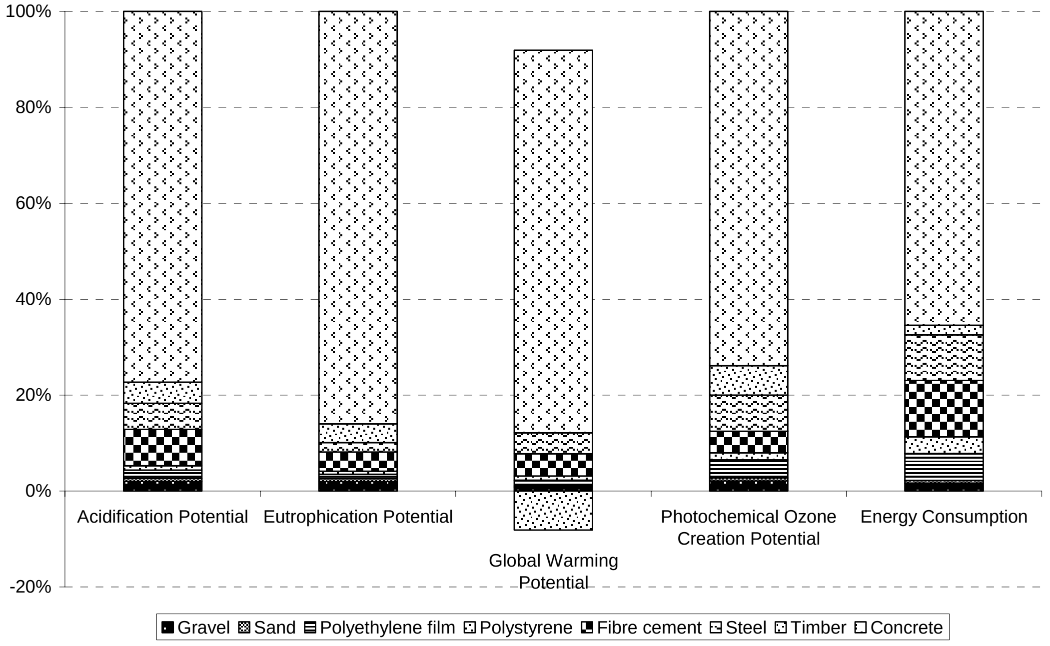

Figure 7: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® foundation system

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

Concrete accounted for the greatest contribution to all environmental impact categories from the foundation system, ranging from 65% (energy consumption) to 86% (eutrophication potential). In terms of the total impact of the building, concrete accounted for 20% and 14% of the eutrophication potential and embodied energy of the construction impact respectively. However, concrete also accounted for 59% and 46% of the mass of the foundations and the Waitakere NOW Home® respectively.

Fibre cement and reinforcing steel were the next largest energy consumers, accounting for 12% and 10% of the embodied energy of the foundations respectively. However they only accounted for 0.5% and 0.7% of the mass of the system respectively.

Polystyrene and Polyethylene damp proof course (DPC) accounted for 3.5% and 5.6% of the total embodied energy of the foundations respectively, but only for 0.02% and 0.04% of the mass of the system respectively.

Sand and gravel accounted for 7% and 24% of the mass of the Waitakere NOW Home® respectively, but only for 0.1% and 0.4% of the total embodied energy of the building respectively.

The materials installed in the flooring component of the foundation system were epoxy sealer, carpet and ceramic tiles. The material with the greatest contribution to the flooring impact for all impact categories was carpet (over 70%), followed by the epoxy sealer applied to the concrete slab. The carpet accounted for 3.3% of the construction energy consumption, and only 0.07% of the mass of the Waitakere NOW Home®. The epoxy sealer accounted for 1.3% of the construction energy consumption, but only for 0.02% of the mass of the NOW Home®.

Ceramic tiles installed in the bathroom had a minimal contribution to the overall impact of the flooring system therefore they will not be discussed further.

External walls

Table 7 and Figure 8 present the contribution to each impact category of the components installed in the external wall system of the Waitakere NOW Home®.

Table 7: Environmental impacts of each component in the Waitakere NOW Home® external wall system

External wall component	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
External finish	5.2	0.5	-748	1.4	9,233
Framing	2.8	0.4	-919	0.4	5,436
Insulation	0.6	0.07	193	0.1	3,153
Internal finish	2.2	0.2	416	0.6	7,704
Total	11	1.0	-1,057	2.4	25,526

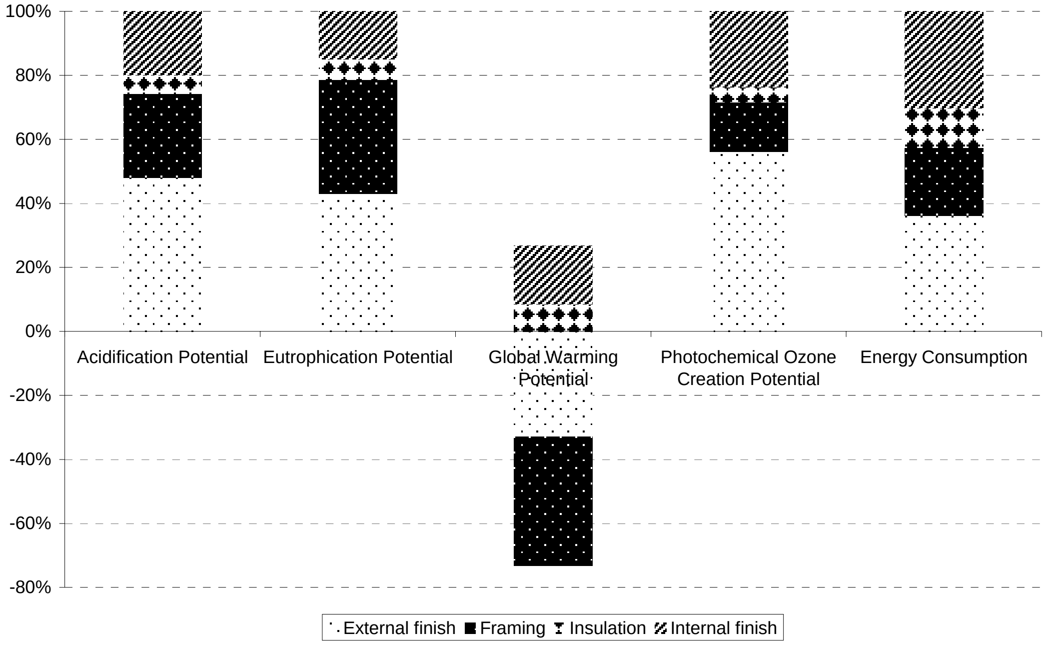

Figure 8: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® external wall system

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. The external and internal finish accounted for the majority of the embodied energy of the external wall system with 36% and 30% respectively. Timber cladding and paint accounted for a large proportion of the external finish energy consumption (49% and 26%, respectively), accounting for 92% and 3% of the mass of the external finish respectively. Paint also accounted for a large contribution to the photochemical ozone creation potential and acidification of the external finish (68% and 57% respectively), accounting for 3% of the mass of the external finish of the system.

Overall, paint contributes 56% to the total photochemical ozone creation potential of the external wall system (including exterior and interior finishes), but only accounts for 1.7% of the mass of the external wall system. This amounts to 12% of the total photochemical ozone creation potential of construction and only 0.07% of the mass of the Waitakere NOW Home®.

Both the external finish and framing in the wall system have a net negative global warming potential. This is due to the stored carbon within the timber in each building component.

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, which amounts to 1.3% of the total embodied energy of the building and 0.1% of the mass of the Waitakere NOW Home®.

Internal walls

Table 8 and Figure 9 present the contribution to each impact category of the materials installed in the internal wall system of the Waitakere NOW Home®.

Table 8: Environmental impacts of each material in the Waitakere NOW Home® internal wall system

Internal wall material	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
Finishing timber	0.04	0.01	-14	0.01	67
Paint	2.0	0.03	112	0.9	2,406
Gypsum board	2.3	0.3	739	0.2	12,919
Framing	3.0	0.4	-981	0.4	4,768
Tiles	0.04	0.003	29	0.003	286
Total	7.3	0.7	-115	1.5	20,446

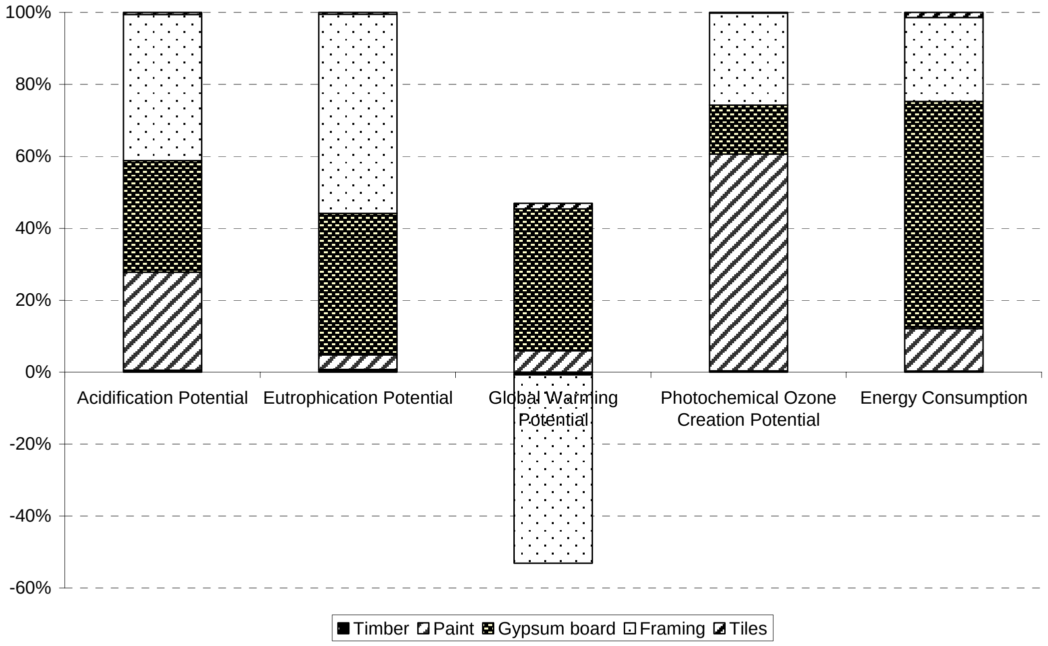

Figure 9: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® internal wall system

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 accounted for the greatest contribution to the photochemical ozone creation potential of the internal wall system (60%), accounting for 1.3% of the mass of the system. This amounts to 8% of the total construction impact but only 0.05% of the mass of the building.

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

Framing installed in the internal wall system accounted for a high proportion of the eutrophication potential of the system (55%), but for 41% of the mass of the system. Framing also accounted for a large net negative global warming potential.

Windows

Table 9 and Figure 10 present the contribution to each impact category of the materials installed in the windows of the Waitakere NOW Home®.

Table 9: Environmental impacts of each material in the Waitakere NOW Home® window system

Window material	AP [kg SO_2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO_2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
Aluminium	1.7	0.04	459	0.2	8,289
Glass	3.8	0.5	811	0.3	8,383
Timber	0.1	0.01	-33	0.01	163
Paint	0.03	0.0004	1.7	0.01	36
Total	5.6	0.6	1237	0.5	16,870

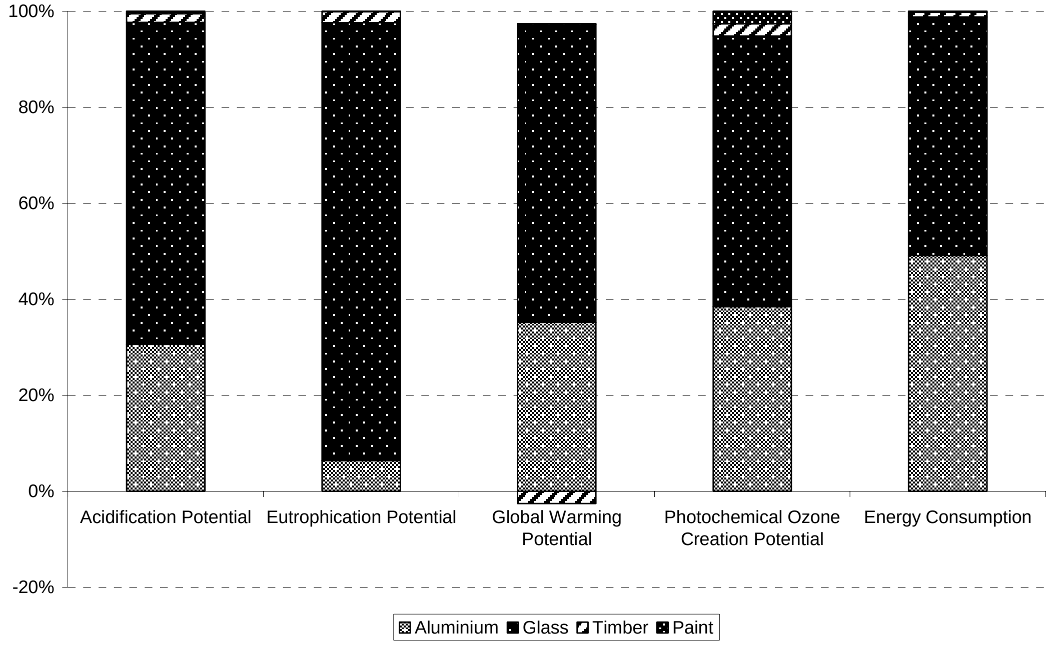

Figure 10: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® window system

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®.

Glass accounted for the greatest contribution for all the impact, ranging from 50% (energy consumption) to 91% (energy consumption), with a contribution of 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.

Note that the aluminium window frames are assumed to be recycled at end of life and the benefits from this have been incorporated in the embodied impact of the material. The recycling potential of aluminium reduces the embodied impact of the material by a certain amount (Table 3). Considering aluminium has a high embodied impact to mass ratio, the impact could have been much greater if the aluminium was not recyclable.

The environmental impact contributions of timber and paint were insignificant, with minimal contributions to the construction impacts of the window system and the Waitakere NOW Home®. Timber had a small net negative global warming potential.

Ceiling

Table 10 and Figure 11 present the contribution to each impact category of the materials or components installed in the ceiling system of the Waitakere NOW Home®.

Table 10: Environmental impacts of each component in the Waitakere NOW Home® ceiling system

Ceiling material	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
Paint	1.3	0.02	73	0.6	1,569
Gypsum board	1.7	0.2	562	0.2	9,818
Steel	0.2	0.02	121	0.03	1,783
Insulation	1.7	0.2	531	0.3	8,658
Total	5.0	0.4	1,287	1.1	21,828

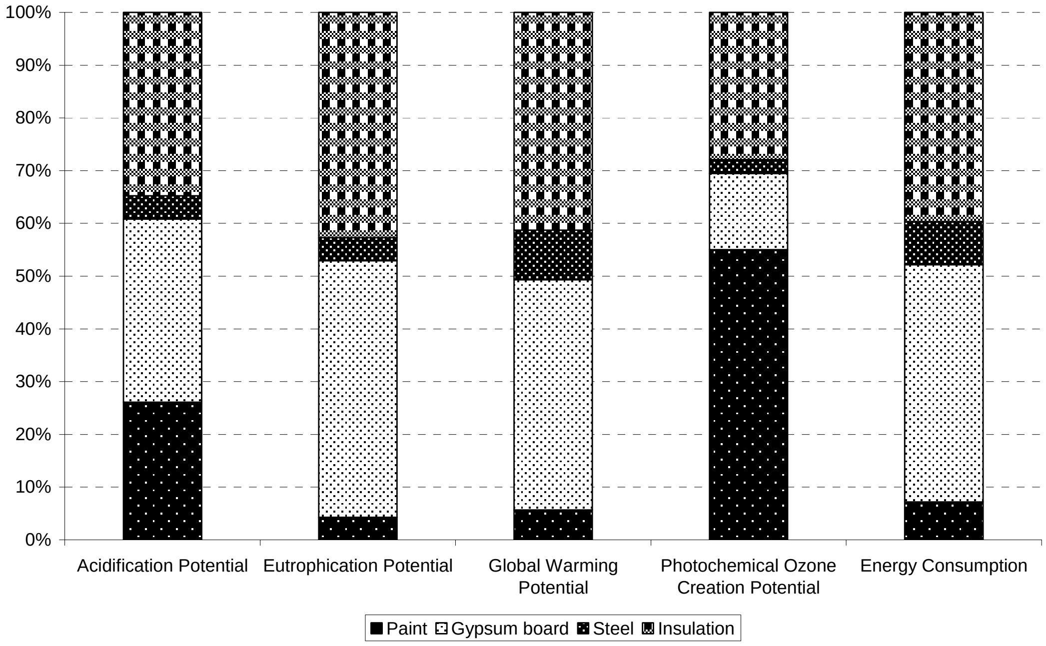

Figure 11: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® ceiling system

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 majority of the energy consumption, eutrophication and global warming potential of the ceiling is attributed to gypsum board and insulation. Gypsum board and insulation account for 45% and 40% of the energy consumption respectively. Similar distributions are shown for eutrophication and global warming potential. Gypsum board accounts for 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.

Roof

Table 11 and Figure 12 present the contribution to each impact category of the materials or components installed in the roof system of the Waitakere NOW Home®.

Table 11: Environmental impacts of each component in the Waitakere NOW Home® roof system

Roof component	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
Fascia guttering	1.3	0.1	439	0.2	6,212
Eaves	0.7	0.1	185	0.1	5,854
Roofing	4.2	0.6	2,017	0.7	24,038
Framing	1.6	0.2	-1,226	1.2	41,688
Total	7.7	1.0	1,413	2.2	77,792

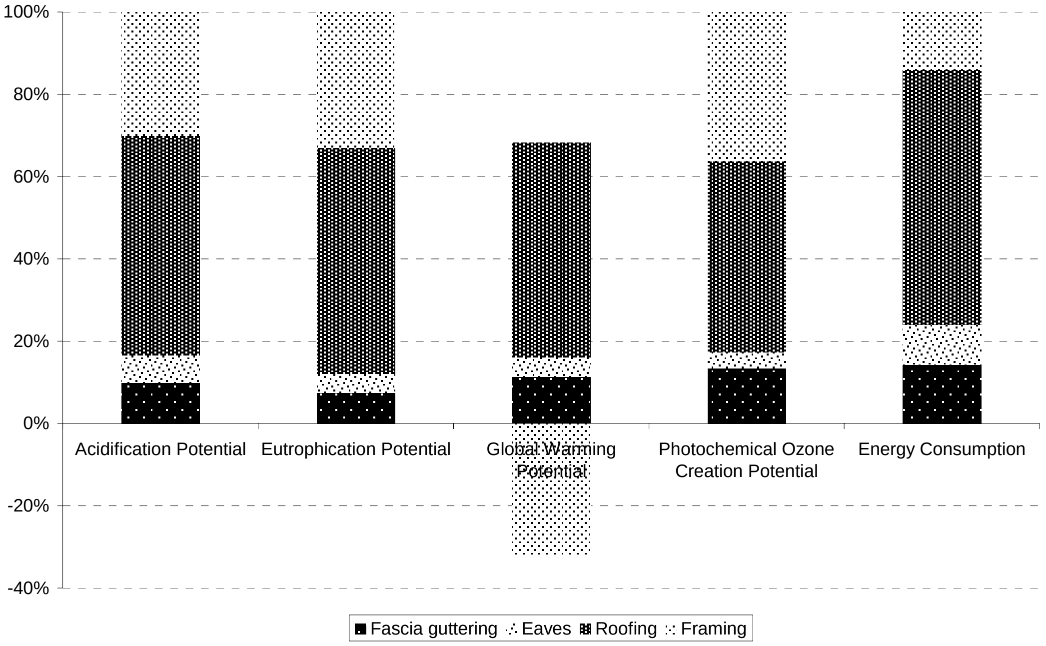

Figure 12: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® roof system

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%). Roofing materials included: concrete tiles, timber battens and building paper. This component accounts for 78% of the mass of the roof system.

Framing accounted for the greatest net negative global warming potential which is due to the CO_2 stored in the timber. The roofing component has a lower global warming potential due to the net negative global warming potential of the timber installed in the component.

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. This amounts to around 5% of the total construction impact for each category and 1.9% of the mass of the Waitakere NOW Home®

The fascia guttering accounted for 14% of the embodied energy of the roof system but only 1.6% of the mass of the system. This amounts to 3% of the energy consumption from construction and only 0.2% of the mass of the NOW Home®.

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.

3.3.4 Sensitivity Analysis of the Waitakere NOW Home® Lifetime

The lifetime of the Waitakere NOW Home® in the base scenario was 100 years. However, in order to identify the sensitivity of the impacts of each life cycle stage to different lifetimes, an alternative scenario was modelled decreasing the lifetime to 50 years, which reflects the minimum code requirements.

In order to maintain clarity, the lifetime analysis was based on a hypothetical situation where the base scenario was set at 50 years and the extended lifetime was 100 years. The purpose of this comparison is to identify whether the difference in lifetime influences the proportion of impact contributed by each life cycle stage of the building.

The main aim is 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.

Table 12 and Figure 13 present the contribution to each impact category of the life cycle stages for 50 and 100-year lifetimes. The life cycle stages that change as the lifetime increases to 100 years are; maintenance, operation, and end of life. The proportion of the construction impact for each category decreases, which is expected as the material quantities do not change as the lifetime is extended from 50 to 100 years.

The maintenance impact increases as greater quantities of materials are required to maintain the building for a longer lifetime. The eaves and roofing components require maintenance in the 100 year lifetime scenario but do not in the 50 year lifetime scenario.

Table 12: Life cycle environmental impacts of the Waitakere NOW Home® with 50 and 100 year lifetimes

Waitakere NOW Home®	**AP**		**EP**		**GWP**		**POCP**		**Energy [MJ]**	
	[kg SO2-Equiv.]		**[kg Phosphate-Equiv.]**		**[kg CO2-Equiv.]**		**[kg Ethene-Equiv.]**			
Lifetime (yrs)	50	100	50	100	50	100	50	100	50	100
Construction	74	74	9.0	9.0	10,980	10,980	12	12	234,106	234,106
Maintenance	45	119	1.8	6.1	5,196	14,869	18	41	104,485	299,176
Operation	193	386	6.2	13	38,766	77,531	6.0	12	936,862	1,873,724
End of life	12	14	1.8	2.0	2,624	3,043	1.7	2.0	25,740	27,950
Total	325	593	19	30	57,566	106,423	37	67	1,291,146	2,424,908

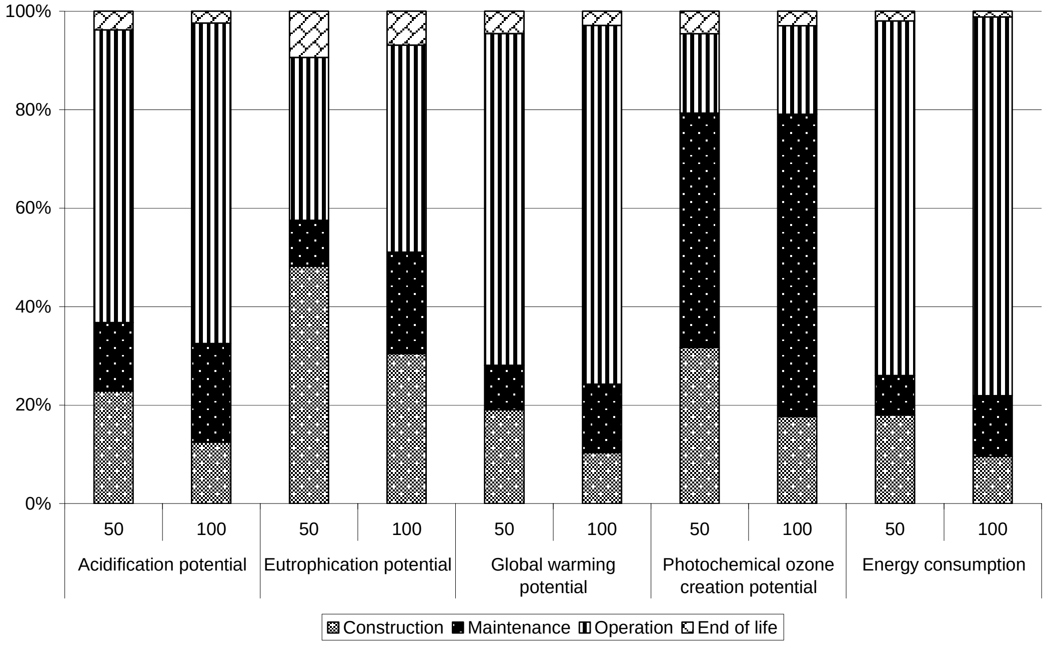

Figure 13: Percentage contribution to life cycle environmental impacts of the Waitakere NOW Home® with a lifetime of 50 and 100 years

Figure 13 shows that the percentage contribution of the maintenance related impact, for each impact category, increases as the lifetime is raised from 50 to 100 years.

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

Though the maintenance impact increases 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. For example, for global warming potential, the impact decreases from 28% to 24% from 50 to 100 years.

This shows that the longer the Waitakere NOW Home® is in operation, 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.

The proportion of the end of life impact for all categories decreases as the lifetime is extended from 50 to 100 years.

System maintenance analysis

The contribution of the maintenance stage to the life cycle impacts range between 8% (energy consumption) to 61% (photochemical ozone creation potential) in the 50-year lifetime scenario. In the 100-year lifetime scenario, the maintenance related impacts ranged from 12% (energy consumption) to 61% (photochemical ozone creation potential) of the total impact of the building.

Table 13 and Figure 14 present the contribution of each maintained system to each impact category for the 50 and 100-year lifetime scenarios.

Table 13: Environmental impacts of each maintained building component of the Waitakere NOW Home® for 50 and 100-year lifetimes

Waitakere NOW Home®	**AP**		**EP**		**GWP**		**POCP**		**Energy [MJ]**	
	[kg SO2-Equiv.]		**[kg Phosphate-Equiv.]**		**[kg CO2-Equiv.]**		**[kg Ethene-Equiv.]**			
Lifetime (yrs)	50	100	50	100	50	100	50	100	50	100
Floors	5.5	12	0.8	1.7	2,657	5,883	0.8	1.7	49,126	108,892
External walls	17	41	0.4	1.3	739	1,067	7.4	17	22,026	59,956
Internals walls	11	26	0.2	0.7	770	2,378	4.9	11	15,878	47,153
Windows	1.5	8.8	0.1	0.9	314	1,874	0.2	0.9	1,841	10,780
Doors	2.8	6.7	0.1	0.2	113	96	1.3	2.8	3,467	8,324
Ceiling	7.2	17	0.1	0.5	522	1,679	3.2	7.1	10,642	32,663
Roof	0.1	5.3	0.01	0.6	46	1,726	0.01	0.8	681	27,999
Integrated Water Systems	0.03	0.09	0.003	0.009	15	46	0.01	0.02	555	1,701
Total	45	118	1.7	6.0	5,177	14,749	18	41	104,216	297,470

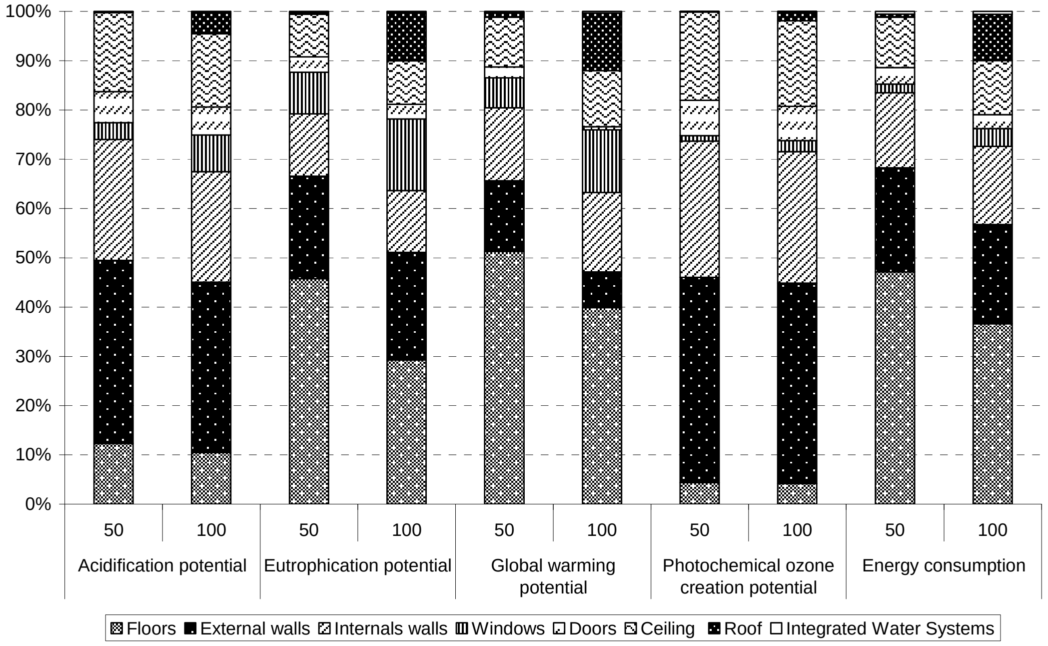

Figure 14: Percentage contribution to environmental impacts of each maintained component of the Waitakere NOW Home® for 50 and 100-year lifetimes

It is noticeable that the external wall system has a large contribution to acidification and photochemical ozone creation potential in both lifetime scenarios. The external wall system accounts for 42% and 41% of the photochemical ozone creation potential in the 50 and 100-year scenarios respectively. This is largely due to repainting. For example, in the 100-year lifetime scenario, paint accounts for 95% of the acidification potential of the external wall system. The internal wall system also accounted for a high proportion of both these impact categories and this was also largely due to repainting.

The floor component accounted for a high proportion of the maintenance related embodied energy, global warming and eutrophication potential in the 50 and 100-year lifetime scenarios. The floor component accounted for around 51% and 40% of the maintenance related global warming potential in the 50 and 100-year scenarios respectively, and around 47% and 37% of the maintenance related energy consumption in the 50 and 100-year scenarios respectively. Around 64% and 36% of the impact of these impact categories is attributed to recarpeting and reapplication of epoxy sealer for the concrete slab respectively.

Maintenance of the window system accounts for a high proportion of the eutrophication potential of the maintenance stage, and increases from 8% to 15% in the 50 and 100-year lifetime scenarios respectively. This is due to the glass which accounted for 91% of the maintenance related eutrophication potential of the window system in the 100-year lifetime scenario, and 70% of the total mass of the materials required to maintain the window system.

The eaves and roofing components are maintained in the 100-year scenario (but not in the 50-year lifetime scenario), which increases the impact of the roof system for all categories as the lifetime is extended from 50 to 100 years. For example, the maintenance related global warming potential of the roof system increases from 0.9% to 12% as the lifetime increases from 50 to 100 years. The maintenance of the eaves and roofing components involves replacing the fibre cement and PVC joiners in the eaves, and the concrete tiles and timber battens in the roofing component.

Maintenance of the ceiling component accounts for a relatively high proportion of the acidification potential of the maintenance stage, around 14% of the total maintenance related impact in both the 50 and 100-year lifetime scenarios. Paint applied to the ceiling accounts for a high proportion of the impact, contributing 97% and 93% to the acidification potential of the ceiling component in the 50 and 100-year lifetime scenarios respectively. Paint applied to the ceiling accounted for 30% and 13% of the mass of the ceiling component in the 50 and 100-year lifetime scenarios respectively. Ceiling paint also accounted for a high proportion of the other impact categories. For example, in the 50-year lifetime scenario, 87% of the maintenance related embodied energy of the ceiling component was attributed to paint.

3.3.5 Alternative NOW Home® Designs

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.

The alternative NOW Home® designs were based on the actual NOW Home® design but with either a different foundation/floor, cladding system, roofing system, or all of these in combination. The alternative NOW Home® designs are listed below:

- 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.

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®.

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^{o}C during morning and evening hours.

Accuracy of ALF (BRANZ, 2000): While there are no direct field study results to verify the ALF method, the SUNCODE computer simulations on which they are based on have been verified with field measurements. A comparison of ALF predictions with several hundred SUNCODE simulations was carried out. ALF tended to be approximately 6% lower in required heating than SUNCADE, with overall accuracy better than ± 10%. This variance is smaller in cooler climates, which is of most relevance to ALF. The accuracy of the ALF method is therefore well within the expected and required limits for basic thermal design.

Although the actual energy consumption of the original NOW Home® was used for the main analysis in this study, for this specific analysis, the original NOW Home® was also modelled in ALF to enable a fair comparison with the alternative NOW Home® designs in different climate zones. Even though the monitoring results, over two years of operation, showed that the heating energy demand of the Waitakere NOW Home® was close to zero, when the NOW Home® was modelled in ALF, the heating demand was around 1,150 kWh in Auckland. This shows that there is a discrepancy between the ALF tool and the monitoring results for the Waitakere NOW Home®. However, the ALF results are still applicable because it is not the absolute heating value that is being assessed, but the *difference* between the heating values of the different NOW Home® designs and locations.

Note that only the 100-year lifespan of the NOW Home® was assessed for this comparison.

Life Cycle Impact of each NOW Home® Design

The distribution of life cycle impact between the construction, operation, maintenance and end of life stages for each building design in Auckland, is shown in Figure 15. In this figure the impact of the actual NOW Home® design for each impact category has been set at 100 and the other NOW Home® designs have been weighted relative to the actual NOW Home® impact. Therefore this figure does not show the absolute impact for each NOW Home® design, but a comparison of impact between each NOW Home® design.

The operational impact in the figure is not comparable with the initial life cycle assessment shown in Figure 5 in section 3.3.1 because only the heating energy demand is included here, whereas heating, lighting and hot water were included in that earlier analysis. Heating energy demand is a suitable indicator for operational impacts in this analysis assuming all the different NOW Home® designs use the same heating device.

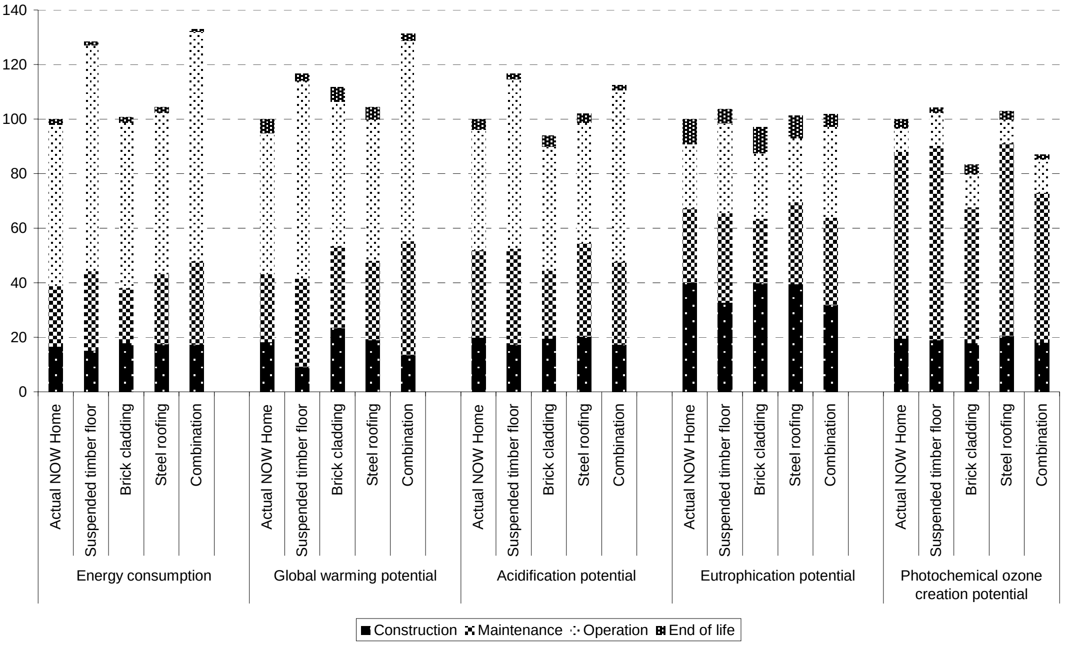

Figure 15: Comparative representation of the life cycle impact of each NOW Home® design, for each impact category, in Auckland

The operation stage is more dominant for the energy consumption, global warming potential and acidification potential for all building designs.

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. Whereas the operational impact for the suspended timber floor and the combination NOW Home® designs 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.

However, even though the suspended timber floor has a higher operational impact, for global warming potential, it has a lower construction impact due to the larger quantities of built-in timber with a large net negative global warming potential.

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 has a relatively higher maintenance related impact for all impact categories, which is caused by the greater quantity of carpet required to maintain the floors. This is not required for the NOW Home® designs with a concrete slab.

Global Warming Potential of each Building in each Climate Zone

The relative life cycle impact of each building design, in each climate zone, is shown in Figure 16. 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.

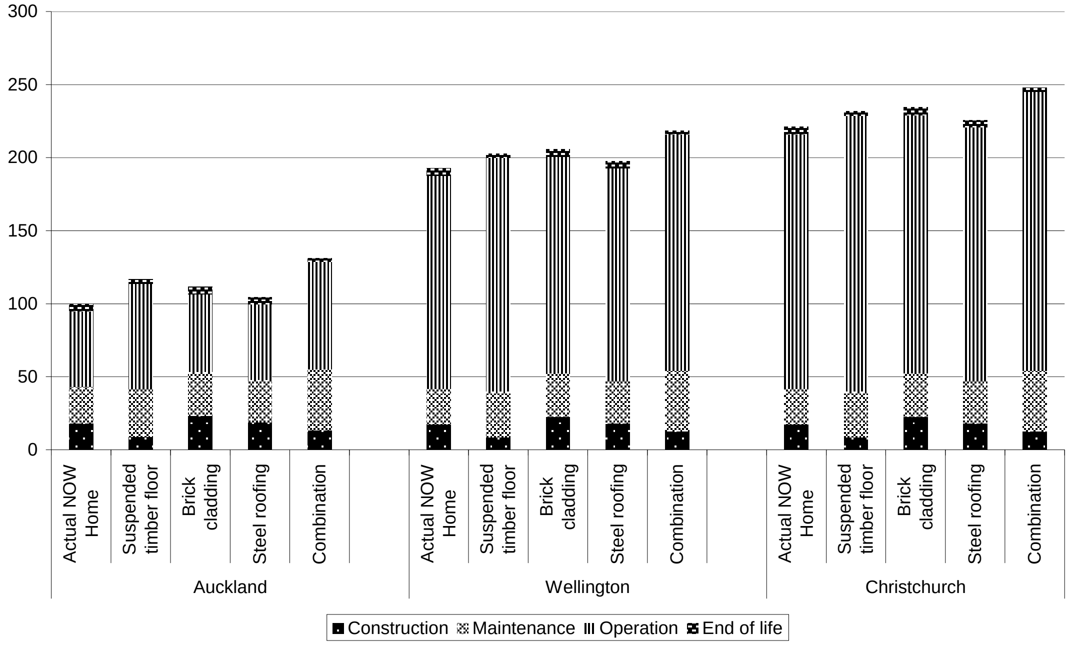

Figure 16: Comparative representation of the life cycle impact of each NOW Home® design, for each impact category, in each climate zone

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. This is caused by the increase of around 120% in operational impact (suspended timber floor) to 183% (actual NOW Home®). The change in operational impact from Wellington to Christchurch is much smaller than the change from Auckland to Wellington.

3.4 Interpretation

This section is an interpretation of the results from the previous section. The distribution of impacts between the life cycle stages will be discussed, along with the systems and materials with high impacts in the Waitakere NOW Home®.

Limitations of the study and areas of future work for Beacon Pathway will be presented at the end of the interpretation section.

3.4.1 Environmental Impacts of Life Cycle Stages

The operational stage of the Waitakere NOW Home® accounted for the greatest contribution to acidification potential, global warming potential and energy consumption of the building, contributing around 65-76% to each of these categories.

The percentage contribution from operation for global warming potential and acidification potential is similar to that of energy consumption because these categories are closely related. Non-renewable energy use is a main contributor to global warming and acidification potential, as most non-renewable energy is fossil fuel based and emissions from combustion are strongly related to these impacts.

The operational reticulated energy consumption of the Waitakere NOW Home® for the 50 and 100-year lifetime scenarios was 136,150 kWh and 272,300 kWh respectively. However, the energy end uses that were included in the operational impact analysis were heating, lighting and hot water (HL+HW), which accounted for 30% and 35% of the total energy consumption of the Waitakere NOW Home® for year one and year two respectively. Hot water accounted for around 70% and 77% of the total HL+HW energy consumption in year one and two respectively.

The construction and maintenance stages were the next biggest contributors to the life cycle impact. The photochemical ozone creation potential of the maintenance stage was relatively high (61%). This was largely due to the reapplication of paint which accounted for a low proportion of the material mass required to maintain the Waitakere NOW Home® (10%). 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. This impact considers the sequestration of CO_2 in the trees, the GHG emissions from production of the timber and decomposition of the timber in landfill, along with the permanent storage of the CO_2 in landfill. The result is a net negative global warming potential. 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.

3.5 Summary and Conclusions

In this study, the Waitakere NOW Home® was analysed using Life Cycle Assessment. The goals of the LCA study were to;

- identify the environmental hot spots of the Waitakere NOW Home® in order to identify the systems that contribute the most to the environmental impacts of a home, and;
- compare the embodied energy in the construction of the Waitakere NOW Home® (cradle to gate) with the operational energy use during the use phase of 100 years;
- provide a benchmark for the development of further NOW homes ®; and
- compare the life cycle impact of the actual NOW Home® design with four alternative NOW Home® designs, in two other climate zones.

A discussion of limitations of the research and recommendations for future research are provided at the end of this section.

Environmental hot spots

The foundation system of the Waitakere NOW Home® accounted for the greatest proportion for eutrophication and global warming potential from construction. This was due to the large quantity of built-in concrete.

The external wall system accounted for a high proportion of the photochemical ozone creation potential from construction due to paint applied for exterior cladding and interior finish. However the system had a large net negative global warming potential because of the built-in timber.

The embodied energy of the window system was reduced by incorporating the benefit from recycling the aluminium framing. The initial embodied impact of the aluminium framing was reduced, for all impact categories, by deducting the amount of impact avoided by producing recycled aluminium that could replace virgin aluminium elsewhere.

The concrete roofing tiles and gypsum wallboard accounted for a high proportion of the embodied energy of the building. This was largely because these materials accounted for a high proportion of the mass of the Waitakere NOW Home®. They had relatively low embodied impact to mass ratios.

The doors, garage door and pergola all accounted for a minor contribution to each impact category. However the polyethylene rainwater tank, which was included in the plumbing system, had relatively high embodied impacts. It was assumed, however, that the tank would not require maintenance throughout the life of the Waitakere NOW Home®. The tank also meant that water was efficiently used.

The materials that accounted for a high proportion of the maintenance related impacts included paint, carpet and epoxy resin. These three have a high impact, in both the 50 and 100-year lifetime scenarios, due to both a relatively large mass, which resulted from regular reapplication, and a high impact per kilogram of material. The epoxy sealer was the only material that was required to maintain the exposed concrete slab, therefore the impact is relatively minimal.

Embodied versus operational energy

The operational stage of the Waitakere NOW Home® was the most dominant stage in terms of global warming potential, embodied energy, and acidification potential of the life cycle, accounting for between 65-76% of the total impact.

The energy end uses that were considered when calculating the total lifetime (100 years) operational energy consumption and operational impacts were heating, lighting and hot water. These end-uses accounted for 30-35% of the total energy consumption of the building for year one and two respectively[5].

This indicates that focus should be placed on reducing the operational energy consumption of the building as well as the embodied impact of the built-in materials.

The construction and maintenance stages were the next largest contributor's to the life cycle impacts. Each had similar contributions to the overall impact, except for acidification potential, where the maintenance stage had the greater impact due to relatively regular repainting.

Alternative NOW Home® designs and locations

The actual NOW Home® design was compared to four alternative NOW Home® designs. The actual NOW Home® design had the lowest life cycle impact for energy consumption and global warming potential. The brick cladding NOW Home® 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 NOW Home® design had a higher maintenance impact due to recarpeting. Therefore it may be useful to explore different flooring materials.

The actual NOW Home® design had the lowest operational impacts which reflected the lower heating demand due to the energy storing capacity of the concrete slab. The suspended timber floor NOW Home® design 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 NOW Home® designs had the lowest life cycle impact in Auckland due to lower heating demand. The operational impact increased from Auckland to Wellington, for all impact categories, by around 120% (suspended timber floor NOW Home® design) to 183% (actual NOW Home®), however the increase in demand between Wellington and Christchurch was not as large.

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[5] ***The use of appliances was excluded since this is not related to the building itself.***

Benchmark

This study is a ‘one off’ study that was undertaken retrospectively and not a comparative study. The study was based on the assumption that the materials were chosen with regard to their sustainability related performance. The results can therefore be used as a benchmark for future homes, but cannot provide an answer on the absolute performance with regard to the environmental impacts.

The maintenance impact increased from 50 to 100 years. However the proportion of the total life cycle impact of the embodied impact of all the materials installed in the building over its whole lifetime (construction and maintenance materials), decreased from 50 to 100 years.

This indicates that the 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.

Limitations of research

The use of European data for some building materials is a limitation of the study. However, the results still provide indicative results that allow a meaningful hot spot analysis.

Future research

The most important next step would be to update the remaining international background data once New Zealand life cycle inventory data is available. With regard to future work on new homes it would also be interesting to further model different materials. This could then be used to inform the development of future NOW homes®.

The study has shown that over a 100-year lifetime of the house, the use phase dominates the environmental performance with 65-76% of the total impacts. This indicates that further research should focus in reducing the energy requirements used for heating and hot water supply. However, reducing the operational energy, will at the same time require more materials and will therefore shift the focus to materials for two reasons. Research on building systems therefore needs to be a priority as well.

Maintenance was identified as another key issue. Research with regard to systems that have a reduced maintenance requirement would therefore have potential to contribute to the environmental improvement of homes.

4 Literature/data sources

Baumann, H & Tillman, A-M 2002, The Hitchhiker's Guide to LCA. An orientation in life cycle assessment methodology and application. Studentliteratur AB.

Bayne, K. et al. 2008, Design Criteria for Retrofit Windows and New Walls. Confidential report SM3570/5 for Beacon Pathway Ltd.

Bayne, K. et al. 2005, NOW Home® Protocols: A Toolkit Documenting the Beacon Approach to Sustainable Residential Design. Confidential report NO103/2 for Beacon Pathway Limited prepared by Scion, Rotorua.

BRANZ 2000: ALF_3 - A design tool for energy efficient houses. Stoecklein, A.; Bassett, M. Building Research Association of New Zealand, Porirua City, New Zealand

Building regulations (1992): (SR 1992/150). Reprint as at 1st February 2009.

CEN TC 350: prEN 15804 (2008). Sustainability of construction works - Environmental Product Declarations - Product category rules . European Committee for Standardisation.

Ecoinvent 2008: The ecoinvent database v2.0. Swiss Centre for Life Cycle Inventories.

Frischknecht, R; Jungbluth, N; Althaus, HJ; Doka, G; Dones, R; Heck, T; Hellweg, S; Hischier, R; Nemecek, T; Rebitzer, G & Spielmann, M. 2004, *The ecoinvent Database: Overview and Methodological Framework*. International Journal of LCA 10 (1) 3 – 9.

Gifford, J.S.; Marvin, N.A.; Dare, P.H. (1998): Assessment of leachate arising from landfill disposal of CCA preservative treated wood. Scion, Rotorua, New Zealand

Guinée, J (ed.) 2002, Handbook On Life cycle assessment. Operational Guide to the ISO Standards. Kluwer Academic Publishers, Dordrecht.

Hauschild, M.; Olsen, S.I.; Hansen, E.; Schmidt A. (2008): *Gone…but not away —addressing the problem of long-term impacts from landfills in LCA*. International Journal of Life Cycle Assessment, 13:547–554

International standardisation organisation 2006. Environmental Management - Life cycle assessment - Principles and Framework. ISO 14040.

International standardisation organisation 2006. Environmental Management - Life cycle assessment – Requirements and Guidelines. ISO 14044.

IPCC (2006): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan

Allison, R and Jaques, RA. November 2005, Waitakere NOW Home® Construction Monitoring Report. Restricted report NO101/2 for Beacon Pathway Limited.

Kellenberger, D & Althaus, H-J 2008, Relevance of simplifications in LCA of building components, Building and Environment xxx (2008) 1–8 (Article in Press).

Micales, J.A.: Skog, K.E. (1997): *The Decomposition of Forest Products in Landfills*. International Biodeterioration and Biodegradation, 39 (2-3), p. 145 – 158.

Ministry for the Environment (MfE, 2009): *New Zealand's Greenhouse Gas Inventory 1990 – 2007*. Submitted to the United Nations Framework Convention on Climate Change. Ministry for the Environment, Wellington, New Zealand.

Nebel, B & Drysdale, D 2009, Methodologies for Carbon Footprinting for the Forestry Sector, Wellington, Scion Research.

PE International (2006): Recycling potential of aluminium sheet. Gabi database 2004. University of Stuttgard, Germany

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

Szalay, Z &Nebel, B 2006, Life Cycle Assessment of a New Zealand house, Wellington, Scion Research.

Tecads, (n.d), Case Study, The NOW home® (brochure).

Trotman, Rachael, May 2008, Waitakere NOW Home®: Occupants Experience of the Home and Implications for Future NOW Homes®, Restricted report NO102/5 for Beacon Pathway Limited.

Vial, E.; Bertrand, M.; Cornillier, C.; Deroubaix, G. (May 2009): *LCA of treated timber: methodological aspects and first results*. The 40th Annual Meeting of International Research Group on Wood Protection, Beijing. Accessed: 25th September 2009. *www.irg-wp.com/IRG40-presentations/IRG%2009-50264.pdf*

Ximenes, F.; Gardner, W.D.; Cowie, A.L. (2008): *The decomposition of wood products in landfills in Sydney*, Australia. Waste Management, Volume 28, Issue 11, 2344-2354

5 Appendix A: Definition of Life Cycle Assessment

ISO 14040 (ISO 14040, 2006) defines LCA as:
"… a technique for assessing the environmental aspects and potential impacts associated with a product, by

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs; and
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

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

Elements of a Life Cycle Assessment

An internationally accepted framework for LCA methodology is defined in AS/NZS ISO 14040 and 14044 (ISO 14044, 2006). These standards define the generic steps which have to be taken when conducting an LCA.

Four different phases can be distinguished.

1) *Goal and Scope Definition:* The goal and scope of the LCA study are clearly defined in relation to the intended application.
2) *Inventory Analysis:* The inventory analysis involves the actual collection of data and the calculation procedures. The relevant inputs and outputs of the analysed product system are quantified and produced as a table.
3) *Impact Assessment:* The impact assessment translates the results of the inventory analysis into environmental impacts (e.g. global warming, acidification). The aim of this phase is to evaluate the significance of potential environmental impacts.
4) *Interpretation:* In this phase conclusions and recommendations for decision makers are drawn from the inventory analysis and the impact assessment.

These can be represented as shown in Figure 17. In practice, LCA involves a series of iterations, as its scope is redefined on the basis of insights gained throughout the study.

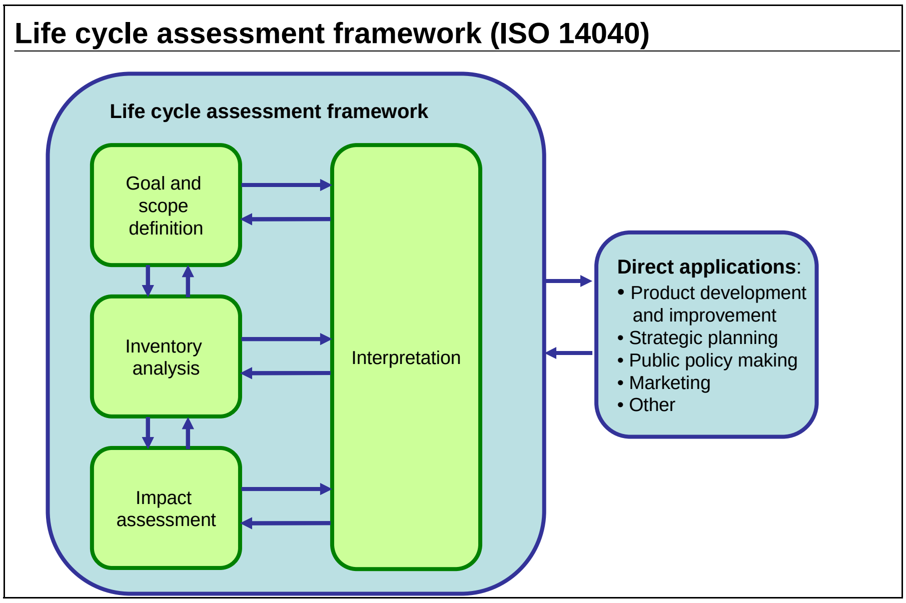

Figure 17: LCA framework (ISO 14040)

5.1.1 Impact Assessment Categories

The environmental impacts of the Waitakere NOW Home® was assessed using CML2001 baseline methodologies (Guinée, 2002). This methodology is widely used in LCA studies and is available in the GaBi LCA software. The CML2001 baseline methodologies allow for analysis of environmental impacts in a number of different impact categories. The impact categories assessed in this study are the following:

- global warming (GWP), expressed in kg CO_2 equivalents;
- acidification (AP), expressed in kg SO_2 equivalents;
- eutrophication (EP), expressed in kg PO_4^{3-} equivalents; and
- photochemical ozone creation (POCP), expressed in kg C_2H_2 equivalents.

The Waitakere NOW Home® was also analysed for primary energy use.

Description of the Impact Categories

- *Global warming potential 100 Years (GWP100)* is caused mainly by CO_2 and CH_4 emissions. These emissions enhance the natural greenhouse effect and lead to an increase in global temperature. During the 20th century, the average global temperature increased by about 0.6°C due to the enhanced greenhouse effect.
- *Acidification potential (AP:)* The most well known effect of acidifying emissions, acid rain, is caused mainly by SO_2 and NO_x emissions to air. Emissions of SO_2 and NO_x can result in strong acids which can have a damaging effect on plants and buildings, and can also influence the soil conditions.
- *Eutrophication potential (EP)* refers to an increase in biomass production due to addition of nutrients, mainly nitrogen and phosphorus, to soil or water. It leads to reduction in species

diversity, often accompanied by massive growth of dominant species, for example “algae bloom”.

- *Photochemical ozone creation potential (POCP)* describes the formation of reactive chemical compounds from NO_x emissions with VOC emissions by the action of sunlight. Ozone (O_3), a form of oxygen, is the most important chemical in this group. In contrast to the protecting role of the ozone layer in the stratosphere, ozone in the troposphere is toxic. Ozone formation, sometimes referred to as “summer smog” is an issue mainly on sunny days in larger cities with a lot of traffic.
- *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.

Furthermore, there are four toxicity categories: namely human toxicity (HTP), marine aquatic ecotoxicity, freshwater aquatic ecotoxicity and terrestrial ecotoxicity which have not been studied. The main reason for not taking toxicity into account is the large uncertainty due to its complexity. Accurate methodologies are therefore still under development.

6 Appendix B: Density and weight of materials used in construction

Table 14: Density of building materials

Building material	**Density (kg/m^3)**
Aluminium	2,700
Bitumen DPC malthoid (0.001m)	1,100
Building paper	0.195kg/m^2
Carpet	2.25kg/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 15: Material quantities in each building component

Building component	**Material**	**Quantity (kg)**	
		Actual NOW Home® design	**Alternative NOW Home® design**
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

	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

	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

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

Table 16: Total weight of building components (excluding maintenance)

Building elements (kg)	Actual NOW Home® design	Alternative NOW Home® design
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 17: Total weight of materials (excluding maintenance)

Materials (kg)	Actual NOW Home® design	Alternative NOW Home® design
Aluminium	191	191
Malthoid	22	22
Brick	0	8448
Building paper	56	56
Carpet	81	231
Concrete	51,090	15,694
Concrete tiles	8,858	0
Copper	23	23
Epoxy resin	20	0

Fibre cement	725	4,98
Glass	596	596
Glulam	81	81
Gravel	26,280	4,812
Gypsum board	5,182	5,182
Insulation fibre glass	436	594
Paint	186	132
Particleboard	0	1,215
PE damp proof membrane	33	5
Polycarbonate	7	7
Polyethylene	250	250
Polypropylene	8	8
Polystyrene	22	0
PVC	2	2
Sand	7,884	1207
Steel	1,017	1623
Tiles	145	145
Timber	8,601	9,137
Vinyl	0	11
Total	111,797	50,172

7 Appendix C: Weight of materials used for maintenance

Table 18: 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	
			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
	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

8 Appendix D: Lifetimes of materials

Table 19: Estimated useful lifetimes of materials

	Material	**Adalberth (Sweden)**	**Jaques as quoted by Mithraratne (New Zealand)**	**Jaques, R. (New Zealand)**	**Rawlinsons Effective 1 April 1993** (New Zealand)	**Fay, as quoted by Mithraratne (Australia)**	**Kirk, S.J. et al., (1995)**	**Johnstone (New Zealand)**	**Mithraratne High, average, low (New Zealand)**	**… study (Switzerland)**	**Page (NZ)**	**Oswald (Austria)**	**Life-spans in this study * Low/ average/ high**
Buildings		50	50		50	100		90	100			100	**50**; 75; **100**
Substructure	Concrete slab	50				> 100		40	50; > 100; > 100	80			**Building life**
Walls	Wall framing (timber)	50			20 (non-load bearing partitions)	> 100		40	50; > 100; > 100	80		50	**Building life**
	Fibre cement							50	40; 50; 60	40	45; 50		40; **50**; 60
	Weather board	30							20; 30; 40	30	50; 70	35	30; **40;** 50
	Brick										80; 100		**80**
	Plasterboard lining							40		40		50	30, **40**; 50
Roof and floor	Timber / steel roof frame	50				> 100			50; > 100; > 100	80			**Building life**

	Material	Adalberth (Sweden)	Jaques as quoted by Mithraratne (New Zealand)	Jaques, R. (New Zealand)	Rawlinsons Effective 1 April 1993 (New Zealand)	Fay, as quoted by Mithraratne (Australia)	Kirk, S.J. et al., (1995)	Johnstone (New Zealand)	Mithraratne High, average, low (New Zealand)	… study (Switzerland)	Page (NZ)	Oswald (Austria)	Life-spans in this study * Low/ average/ high
	Plasterboard ceiling lining				20	> 100			20; > 100; > 100	30		35	30; **40;** 50
	Steel roofing sheets, battens					40		50	30; 40; 50		20; 40; 50		30; **40**; 50
	Concrete tiles and battens	30				> 100			30; > 100; > 100	50	60; 75; 90		30; **60**; 90
	Down pipes (PVC)	30	30			20		25	15; 20; 30				20; **25**;30
	Spouting						40						**40**
Finishes	Carpet	17 (plastic)			15.5 (nylon)	12		10 (wool)	5; 12; 15 (wool)	10			5; **10**; 15 (plastic)
	Vinyl	17	15		10	30		10	10; 17; 30	25			10; **15**; 30
	Epoxy resin			7									**7**

	Material	**Adalberth (Sweden)**	**Jaques as quoted by Mithraratne (New Zealand)**	**Jaques, R. (New Zealand)**	**Rawlinsons Effective 1 April 1993** (New Zealand)	**Fay, as quoted by Mithraratne (Australia)**	**Kirk, S.J. et al., (1995)**	**Johnstone (New Zealand)**	**Mithraratne High, average, low (New Zealand)**	**… study (Switzerland)**	**Page (NZ)**	**Oswald (Austria)**	**Life-spans in this study * Low/ average/ high**
	Interior paint doors, trim, ceiling	10			5 (other)	8		8	6; 8; 10			7	6; **8**; 10
	External paint cladding, doors	10	10			8		8	6; 8; 10		7 (brick); 8; 10 (WB and FC)	5	6; **8**; 10
Joinery	Window frames, glazing	30 (timber)	30 (Alu)			60 (Alu)		40 (Alu)	30; 60; 65 (Alu)			35	30; **40**; 60
	Internal doors, frames	30				60			30; 60; 65	35			30; **40**; 60

* assumed lifetime in **bold**