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Life Cycle Assessment of the Waitakere NOW Home® and two Papakowhai Renovation homes

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About This Report

Title

Life Cycle Assessment of the Waitakere NOW Home® and two Papakowhai Renovation homes

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Abstract

This report provides an assessment of the environmental impacts of the Waitakere NOW Home® and two Papakowhai Renovation homes 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 homes were modelled using international data, as New Zealand specific data is not available at this stage.

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 63-71% of the total impact. The concrete foundation of the Waitakere NOW Home® accounted for the greatest proportion of the acidification potential, eutrophication potential, and global warming potential of the building. In the House 2 renovation, the main environmental impacts were from the glass wool in the insulation materials. Glass wool is the dominant contributor to all environmental impacts in House 2, due to the large amount of insulation materials installed in relation to the other materials used. In the House 10 renovation, the main contributors to the environmental impacts are glass wool, glass, and aluminium.

Reference

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1 Executive Summary

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

The goals of the LCA studies were:

- To identify the environmental hot spots of the Waitakere NOW Home® and the Papakowhai Renovation projects in order to identify the systems that contribute the most to the environmental impacts of a home.
- To compare the embodied energy in the construction of the Waitakere NOW Home® and the Papakowhai Renovation projects (cradle to gate) with the operational energy use during the use phase of 100 years.
- To provide a benchmark for the development of further new home and renovation projects.

The use of European data due to the lack of New Zealand-specific life-cycle inventory data for the building materials is a limitation of the study. However, the results still provide indicative results that allow a meaningful hot-spot analysis.

Waitakere NOW Home ®

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 the life-cycle impacts. 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 acidification potential, where the maintenance stage had a greater impact, caused largely by reapplication of paint. The foundation of the Waitakere NOW Home® accounted for the greatest proportion of the total acidification potential, eutrophication potential, and global warming potential of the building, which was mainly due to the large quantity of concrete in the foundation. The wall system of the Waitakere NOW Home® (external and internal) accounted for the greatest proportion of the total embodied energy and photochemical ozone creation potential of the building, which was largely due to the timber framing and weatherboard cladding.

Embodied versus operational energy

The use phase of the Waitakere NOW Home®, including heating 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 63-71% of the total impact.

Benchmark

This is a ‘one-off’ study undertaken retrospectively, and not a comparative study. It was based on the assumption that the materials were chosen for 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.

Papakowhai Renovation homes

Environmental hotspots

Glass wool is the predominant contributor to the environmental impacts of the House 2 renovation, and is a significant contributor to the impacts of the House 10 renovation as well. This is due to the large quantity of glass wool installed in both houses.

In the House 10 renovation, the main contributors to the environmental impacts are glass wool, glass, and aluminium. Steel contributes strongly to the eutrophication potential of the House 10 renovations and steel and copper both have contributions disproportionately large in comparison to their contributions by mass.

Embodied versus operational energy

The embodied energy of the renovations was smaller than the heating operational energy over 20 years for House 2, but greater for House 10. This is primarily due to the extent of the renovations for each house. However, the LCA study does not take the increased comfort level into account. A true comparison would need to be based on the theoretical energy requirements prior to the renovation to bring the indoor temperature to the same level following the renovation. An analysis of the operational energy *savings* with the embodied energy of the two Papakowhai Renovation homes would have been beneficial, as this would have given insight into the relationship between the extent and type of renovation that yields the greatest energy savings. This analysis was not possible, however, as the average indoor temperature was different pre- and post renovation, and the difference in operational energy savings before and after the renovations was therefore not a meaningful result. It is therefore not possible to draw conclusions regarding the relationship between the extent of renovations and the resultant energy savings from a life cycle point of view.

Benchmark

A comparison of House 10 with an extended lifespan and the Waitakere NOW Home® indicates that, from an environmental and energy perspective, it is better to renovate an existing house and therefore extend its lifespan, than build a new house. The uncertainties in this analysis are high, as House 10 and Waitakere NOW Home® are two specific examples, and do not represent the average or generic New Zealand home. This result therefore needs to be confirmed using analysis from a wider sample of New Zealand homes.

Future research

- Update the results data once New Zealand life cycle inventory data is available.
- Model different materials to inform the development of future new home and renovation projects.
- Further research to reduce the energy requirements for heating and hot water supply.
- 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 needs to be a priority as well.
- Research with regard to systems that have a reduced maintenance requirement would therefore have potential to contribute to the environmental improvement of homes.
- Research to utilise the relatively high embodied energy in timber at the end of life.

2 Introduction

2.1 Background

Beacon Pathway Limited is a research consortium which 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 HSS High Standard of Sustainability® by 2012.
2) Every new, or 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 which aim to show that sustainable, affordable, and desirable homes can be built now using available design concepts, materials, and products.

The Waitakere NOW Home® project aimed to point the way for future housing design and construction by using materials and technology now readily available. Within Beacon, two related projects were undertaken – the NOW Home® project in Waitakere City, and the Papakowhai Renovation project.

In the Papakowhai Renovation project, nine existing houses in Papakowhai (Porirua), were renovated to *"…identify the best (most cost effective and easy to implement) packages and combinations of renovation options to significantly improve the standard of sustainability of the homes…"* (Burgess *et al.* 2008).

One way of analysing and evaluating the sustainability and environmental performance of the Waitakere NOW Home® and the Papakowhai Renovation homes 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® and two of the nine Papakowhai Renovation homes were analysed using Life Cycle Assessment in order to:

- Provide insight into the environmental hot spots of the Waitakere NOW Home® and the renovations in the two Papakowhai Renovation homes.
- Compare the embodied energy of the home/renovations to the operational energy of the homes.

- 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®.

As well as addressing the above criteria, this report also describes the methodology, underlying data, and assumptions used in the Life Cycle Assessment of the homes.

2.2 Life Cycle Assessment

Life cycle assessment (LCA) is based on the concept of integrating consumption and production strategies over the whole lifecycle. 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 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 hotspots in building construction, use and disposal. LCA can also identify hotspots 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 One for an overview of the methodology. The methodology has been described in more detail in the following papers:

2.3 Structure of this report

This report is divided into two parts. In the first part the LCA of the Waitakere NOW Home® is described, including the four phases of the Life Cycle Assessment; *Goal and Scope definition, Inventory analysis, Impact assessment,* and *Interpretation.* The LCA for the Papakowhai Renovation homes is presented in part two. The summary and conclusions gained from both studies are presented at the end of each part.

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 for 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.
- Built from materials chosen for integrity and durability to maintain capital value and ensure weather-tightness.

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 identify the systems which contribute the most to the environmental impacts of a home.
- To compare the embodied energy in the construction of the Waitakere NOW Home® (cradle to gate) with the operational energy use during the use phase.
- To provide a benchmark for the development of further NOW Home®.

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.

The provision of infrastructure and capital goods, such as roads, trucks for transport, machinery, etc., was not considered. 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 taken into account.

Installation and deconstruction of the house have been excluded from the analysis because their contribution over the whole life cycle can be assumed to be minimal (Kellenberger & Althaus 2008).

Maintenance has been included in the study in two scenarios: for useful life 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 standard set by the Building Code. 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.

The main focus of the project was on the structural systems of the house, i.e., building envelope and internal walls. Materials used for services such as electricity, lighting, extractor fans, solar hot water system etc., have been excluded since they are not subject to material choices. However, the energy savings from installing these devices were considered for this study. Site preparation (excavation), as well as the boxing around the concrete slab, have been included in the study. Landscaping was excluded because it is not related to the building itself.

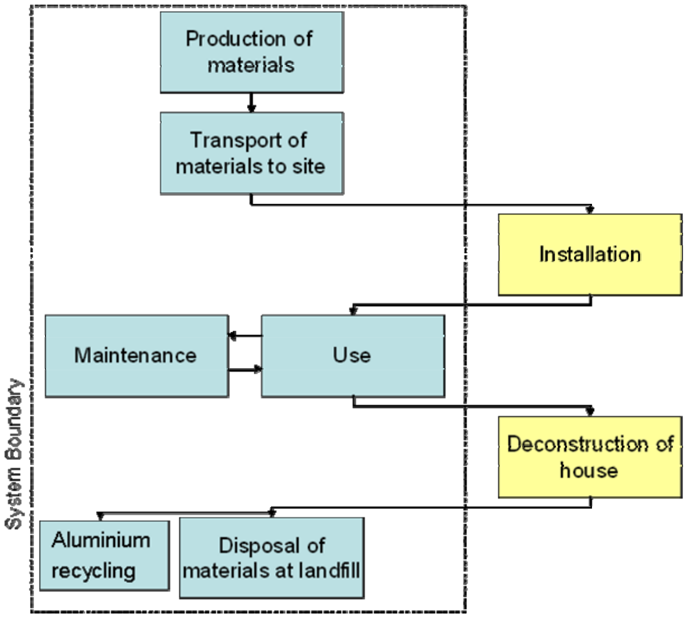

Figure 1: System boundary of the Waitakere NOW Home®

3.1.3 Functional Unit

The functional unit is the Waitakere NOW Home® itself over a 100-year/50-year period in New Zealand and as a home for a family of four. Heating 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.

3.1.4.1 Input – output data

A comprehensive list of all material quantities was not available for the Waitakere NOW Home®, which meant some had to be calculated. Material quantities were calculated for the following building systems: floor/foundations, walls, doors, windows, ceiling and roof, garage door, pergola, and integrated water systems. Landscaping was excluded from the assessment. Integrated water systems excluded the solar heating system but included: copper piping, Valsir down-pipes, and the polyethylene rainwater tank.

The majority of information regarding materials installed in the Waitakere NOW Home® was available from invoices for work carried out. 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 labour-only cost.

Material quantities have been calculated for the Waitakere NOW Home® based on documents provided and personal communication with stakeholders. All efforts to determine accurate material quantities were made. A quality check was carried out between Waitakere NOW Home® material estimates 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.

3.1.4.2 Life cycle inventory data

New Zealand specific life-cycle inventory data for building materials is currently not available. The life cycle inventory data used in this study is therefore 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 and as well as the emissions related to energy use and production. Capital equipment is excluded[1].

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

The documentation describes the production process, applied boundary conditions, allocation rules etc., for each product. The database is compliant with the ISO Standards 14040 and 14044.

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 is then used as an input to 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 analysed in this study are defined below, along with the components within each system:

1) Floor/foundations
    - Hard fill
    - Concrete slab and footings (includes timber boxing)
    - Concrete slab insulation
    - Flooring materials (includes hydro coat epoxy sealer, carpet and tiles)
2) External walls (part of building envelope)
    - Exterior finish (i.e., timber weatherboard cladding etc.)
    - Framing
    - Interior finish (i.e., internal gypsum board lining, skirting etc.)
    - Insulation

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

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 etc.)
    - Insulation
    - Framing
    - Roofing (i.e., concrète tiles, battens etc.)
    - Eaves (i.e., hardisoffit, 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 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 cubic metres, square meters, length, and 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, 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 these stumps. This situation was deemed to be 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 either from the company from which the material was purchased or the thickness was assumed. Tiles installed in the kitchen and bathrooms are an example of this, with the company supplying information.

In cases where no information was provided, various methods 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, 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 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 26 (Appendix Two). 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.

3.2.3 Material quantities

A breakdown of material quantities in each building system is presented in Table 27 (Appendix Three). Figure 2 presents the percentage contribution by weight of each system in the Waitakere NOW Home®. The floor/foundation system has the greatest contribution to total mass (78%). The ceiling and roof (13%), external wall (4%) and internal wall (4%) systems are the next largest contributors, predominantly from the concrete roofing tiles installed for roofing and the large quantities of built-in timber in the walls. The window system contributed 1% to total weight, mainly from aluminium window frames and a large mass of glass due to double glazing.

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

Table 28 (Appendix Two) presents the total weight of each building system in the Waitakere NOW Home®.

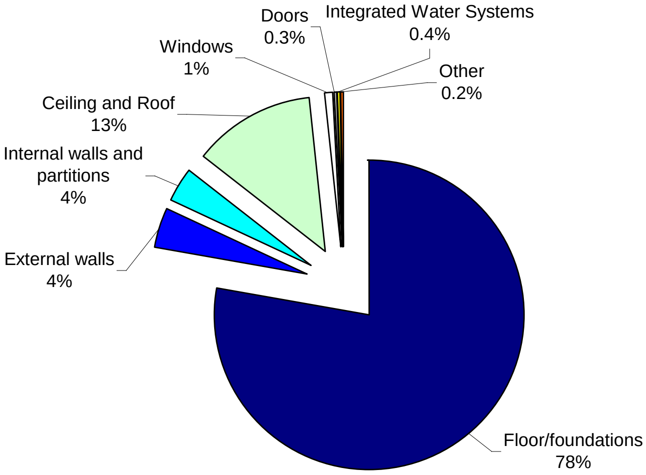

Figure 2: *Percentage contribution, by weight of building systems in the Waitakere NOW Home®*

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. Gravel 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.

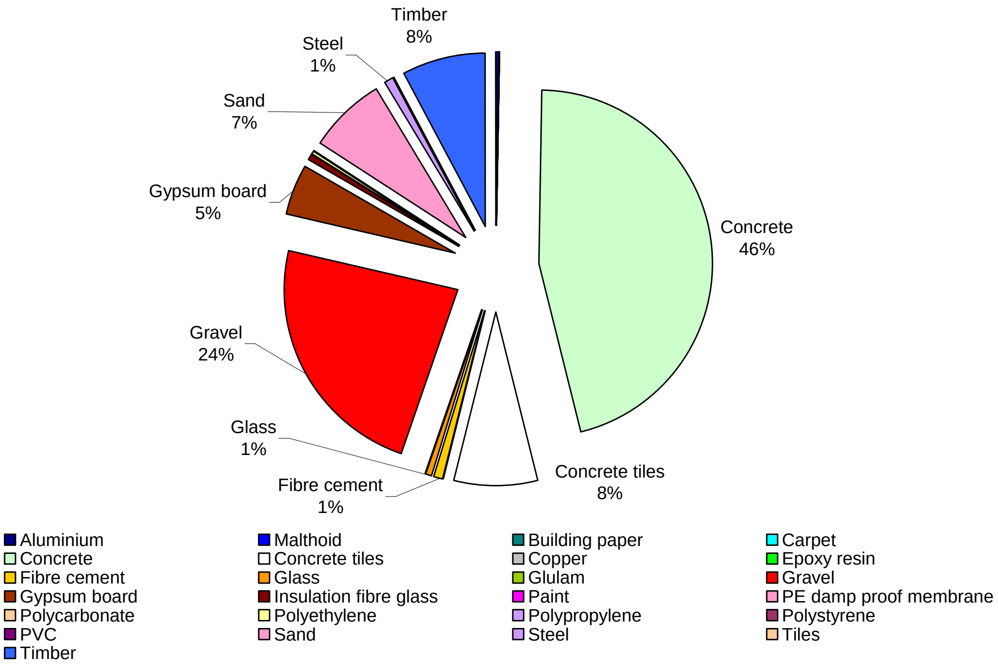

Figure 3: Percentage contribution, by weight of materials installed in the Waitakere NOW Home® (only materials contributing 1% or more have been labelled)

3.2.4 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 2,448 kg of waste material. Of this, 189 kg (8%) was diverted from landfill. Materials diverted from landfill 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 material 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***

Material	Final weight (kg)
Steel scrap	69
Miscellaneous	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

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

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 (e.g., 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 as, ultimately, all materials are sent to landfill at the end of the building's life. This is possible because 92% of waste was 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.

3.2.5 Transport

An average transport distance of 50 km was used for all materials transported to the building site. Even 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 significantly alter the results.

3.2.6 Maintenance

Maintenance activities, including everyday measures such as repairs or decorating as well as heavy maintenance, 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.

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 life spans and replacement cycles.

A maintenance schedule was developed for the Waitakere NOW Home® (based on 100- and 50-year lifetimes) using material lifetimes obtained Szalay and Nebel (2006).

Table 31 (Appendix Four) 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® during a 100- and 50-year lifetime are presented in Table 30 (Appendix Three).

It was assumed that identical materials would be used to replace materials in the Waitakere NOW Home®.

It was also assumed that fibre-cement in the eaves would have the same lifetime as fibre-cement in external walls, i.e., 50 years, and polypropylene down-pipes would have the same life span as the PVC down-pipes, i.e., 25 years. The polyethylene rainwater tank was not included in the maintenance schedule.

3.2.7 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 gives 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 house, whereas energy use from appliances, such as the stove for cooking and television for entertainment, are not directly related to the design and are thus disregarded.

The total annual reticulated energy consumption of the Waitakere NOW Home® for years one and 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 years one and two respectively.

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

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

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. Therefore the average was calculated by assuming the energy consumption of a third year of operation was 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 scaled up 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.

3.2.8 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 initial embodied impact of aluminium window framing is generally high and recycling is a viable option for the material. Therefore, aluminium window framing was recycled at the end of life stage, and the benefits from this were considered.

Concrete roofing tiles and timber weatherboards may also be recycled, however this was not considered as the initial embodied impact of these materials is relatively low and therefore recycling would not have a significant influence on reducing the overall life cycle impact. However, the dataset for timber is based on the assumption that timber will be incinerated at its end of life, which is common practice in Europe. The dataset therefore accounts for the energy stored in the timber, which is shown as renewable energy. This influences the results in two ways – firstly the embodied energy is relatively high and, secondly, the contribution of renewable energy for timber is very high.

The total mass of materials in the Waitakere NOW Home® sent to landfill was 133,885 kg (100 yrs) and 115,278 kg (50 yrs). This includes 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.

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:

- Global warming (GWP)
- Acidification (AP)
- Eutrophication (EP)
- 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 years and 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 3 and Figure 4 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 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.

Waitakere NOW Home®	**AP**	**EP**	**GWP**	**POCP**	**Energy [MJ]**
	[kg SO2-Equiv.]	**[kg Phosphate-Equiv.]**	**[kg CO2-Equiv.]**	**[kg Ethene-Equiv.]**	
Construction	71	8.4	23,189	13	399,427
Maintenance	125	6.5	22,763	10	426,677
Operation	386	13	77,531	12	1,873,724
End of life	-2.7	1.9	-629	0.4	-51,130
Total	578	29	122,855	36	2,648,699

Table 3: Life cycle environmental impacts of the Waitakere NOW Home®

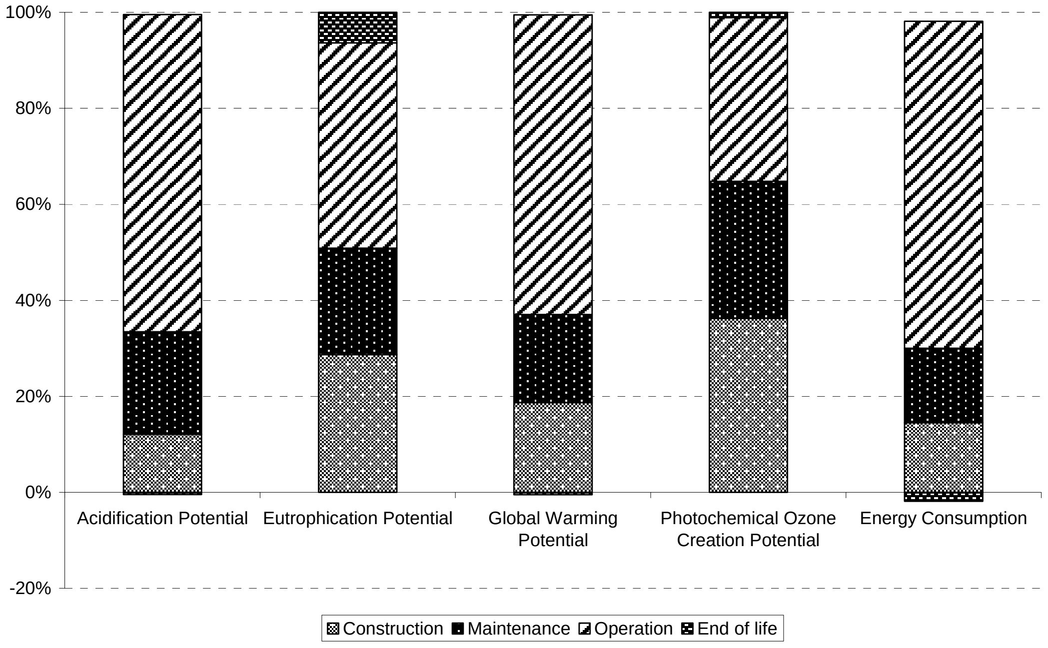

Figure 4: Percentage contribution to environmental impacts of each life cycle stage of the Waitakere NOW Home®

The use phase contributes the greatest impact for acidification potential, global warming potential, and energy consumption, being all similar at around 63-71%. However the operational impact for eutrophication potential and photochemical ozone creation potential was only 45% and 33% respectively.

The construction and maintenance stages were the next largest contributors, both having similar contributions to the total impact. However the acidification potential of the maintenance stage was slightly greater than the construction stage impact. The construction stage ranged from 12% (acidification potential) to 36% (photochemical ozone creation potential) of the total life cycle impact, and the maintenance stage ranged from 16% (energy consumption) to 28% (photochemical ozone creation potential) of the total life cycle impact.

The eutrophication potential and photochemical ozone creation potential of the construction stage are noticeably higher than the other impact categories, contributing 29% and 36% to the total impact of the life cycle respectively. Construction includes transport of materials to the site, which contributes 2.6% of the embodied energy of the construction stage, but only 0.4% of the total embodied energy of the life cycle. The global warming potential of the transport component of the construction stage contributes 3.1% of the total construction impact and only 0.6% of the total global warming potential of the life cycle.

The impact contribution from transport to the total maintenance-related impact was similar to the transport contribution of the construction stage, 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. The end of life stage had the smallest contribution to the overall life cycle impact, and in some cases it had a negative impact. This is a reflection of the benefits from recycling the aluminium window frames at the end of life stage.
Further discussion of the end of life impact is presented in section 3.4.1.

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 which account for high percentage contributions are analysed further in Section 3.3.3.

Table 4 and Figure 5 present the contribution to each impact category of the building systems analysed in the Waitakere NOW Home®. The main contributors include floor/foundations, external/internal walls, ceiling and roof, windows, and the integrated water system.

Waitakere NOW Home® system	**AP**	**EP**	**GWP**	**POCP**	**Energy [MJ]**
	[kg SO2-Equiv.]	**[kg Phosphate-Equiv.]**	**[kg CO2-Equiv.]**	**[kg Ethene-Equiv.]**	
Floor/foundations	16	2.3	7,886	1.8	69,193
External walls	6.9	0.5	2,321	2.2	80,834
Internal walls	4.3	0.3	1,429	1.1	45,480
Ceiling and Roof	11	1.3	4,972	2.6	98,100
Windows	14	1.3	4,201	1.9	53,773
Doors	1.0	0.05	223	0.2	7,405
Integrated Water Systems	3.5	0.4	605	1.7	19,910
Other components	0.5	0.1	236	0.1	6,035
Total	58	6.2	21,873	12	380,729

Table 4: Environmental impacts of each building system in the Waitakere NOW Home® and other components

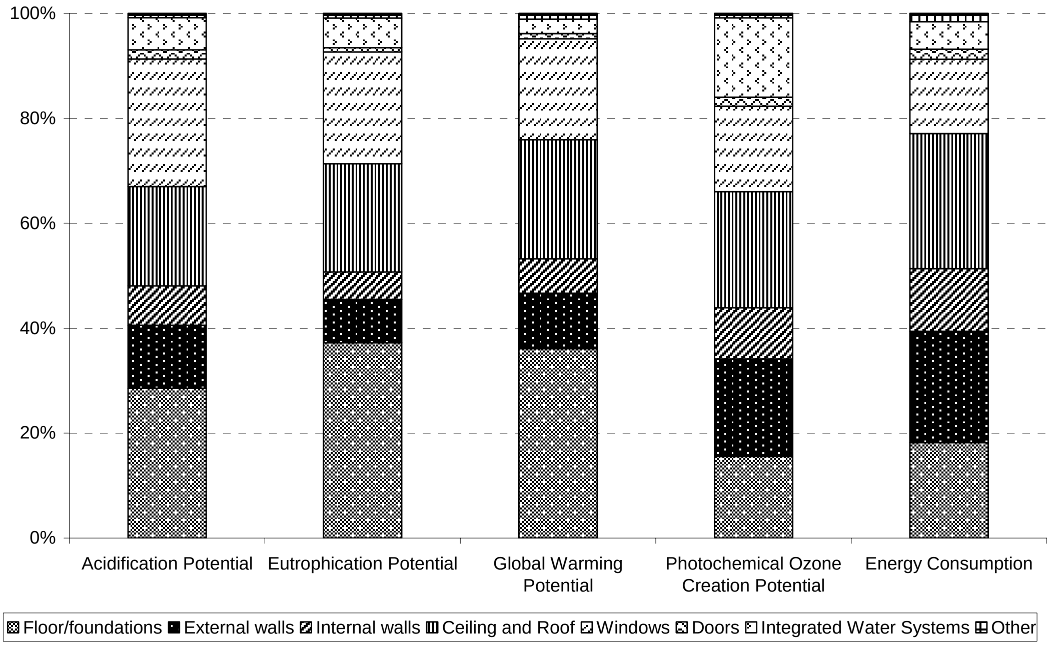

Figure 5: Percentage contribution to environmental impacts of each building system in the Waitakere NOW Home®

The floor/foundation system was the main contributor for acidification potential, eutrophication potential, and global warming potential, ranging between 28% and 37% of the total impact of the building.

The wall system (external and internal) was the main contributor for photochemical ozone creation potential and embodied energy, accounting for 28% and 33% of the impact of the building respectively, however external walls accounted for around 65% of the impact of the wall system for both categories.

The ceiling/roof and windows systems were the next largest contributors. The ceiling and roof system contributed between 19% (acidification potential) to 26% (energy consumption) of the total impact of the building, and the window system contributed between 14% (energy consumption) to 24% (acidification potential) of the total impact.

Further discussion of each system is presented in Section 3.3.3, with identification of the materials that have significant contribution to the embodied impact of systems. The proportion of renewable and non-renewable embodied energy of materials in the wall and ceiling and roof systems will also be discussed.

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.

3.3.3 Hot spot analysis of systems

This section highlights the systems and materials that account for a significant contribution to the embodied 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/mass basis. The assessment of the maintenance related impacts in the 50- and 100-year lifetime scenarios are 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®.

Table 5 presents the percentage contribution to each impact category of the building systems analysed in this section. The integrated water system accounts for around 5% of the embodied energy of the construction phase, making it a relatively significant contributor; however, a hotspot analysis was not required because this was largely from 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.

Waitakere NOW Home® system	**AP [kg SO 2-Equiv.]**	**EP [kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**	**POCP [kg Ethene-Equiv.]**	**Energy [MJ]**
Floor/foundations	29%	37%	36%	16%	18%
Ceiling and Roof	19%	21%	23%	22%	26%
Windows	24%	21%	19%	16%	14%
External walls	12%	8%	11%	19%	21%
Internal walls	7%	5%	7%	10%	12%

Table 5: Percentage contribution to environmental impacts of high impact systems in the Waitakere NOW Home®

3.3.3.2 Floor/foundations

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

Floor/foundations material	**AP [kg SO2-Equiv.]**	**EP [kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**	**POCP [kg Ethene-Equiv.]**	**Energy [MJ]**
Gravel	0.3	0.04	55	0.03	859
Sand	0.1	0.01	17	0.01	258
Polyethylene film	0.2	0.01	76	0.03	2,646
Polystyrene	0.1	0.01	57	0.02	1,751
Fibre cement	1.0	0.1	579	0.2	7,218
Steel	1.2	0.1	505	0.2	7,927
Timber	0.3	0.03	156	0.2	6,887
Concrete	12	1.8	5,864	1.0	30,894
Hydrocoat epoxy sealer	0.3	0.05	174	0.04	2,974
Carpet	0.9	0.1	396	0.1	7,686
Tiles	0.01	0.001	6.9	0.001	96
Total	16	2.3	7,886	1.8	69,193

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

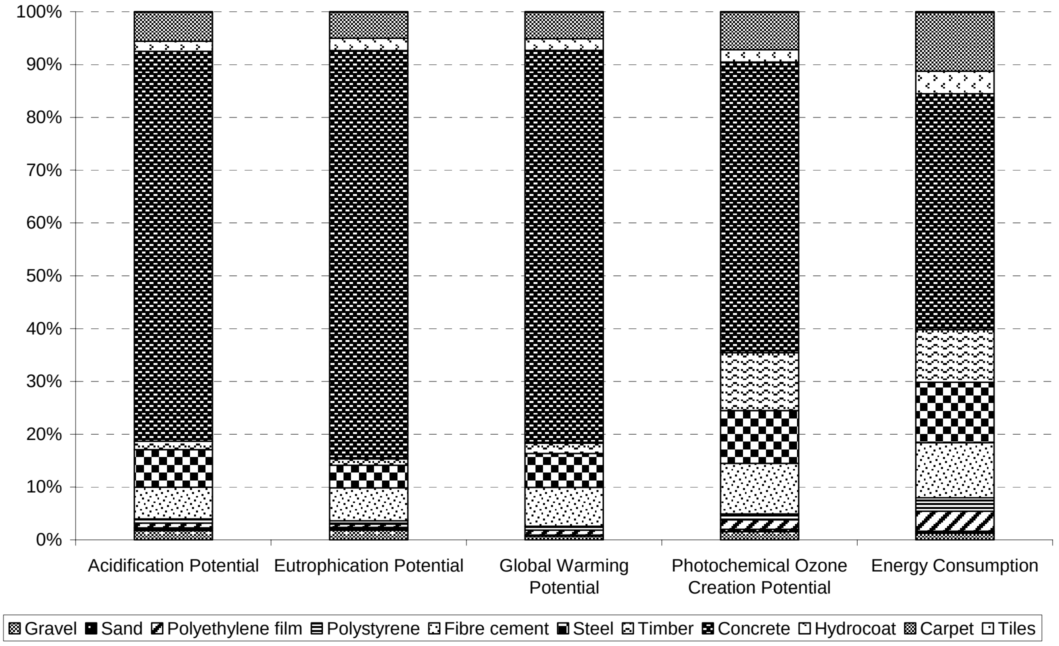

Figure 6: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® floor/foundation system

The contribution of the floor/foundation system to the total impact of the building ranged from 16% (photochemical ozone creation potential) to 37% (eutrophication potential). The system accounted for 18% of the embodied energy of the building, but accounted for 78% of the total mass of the Waitakere NOW Home®.

Concrete accounted for the greatest contribution to all environmental impact categories of the floor/foundations, ranging from 45% (energy consumption) to 77% (eutrophication potential). In terms of the total impact of the building, concrete accounted for 29% of the eutrophication potential and 8.1% of the embodied energy of the building. However, concrete also accounted for 59% and 46% of the mass of the floor/foundations and the Waitakere NOW Home® respectively.

Fibre cement and reinforcing steel were the next largest energy consumers, accounting for 10% and 11% of the embodied energy of the floor/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 2.5% and 3.8% of the total embodied energy of the floor/foundations respectively but only accounted 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 accounted for 0.1% and 0.2% of the total embodied energy of the building respectively.

The materials in the flooring component of the floor/foundation system were hydrocoat epoxy sealer, carpet, and tiles. The material with the greatest contribution to all impact categories was carpet, followed by the hydro coat epoxy sealer applied to the concrete slab.

The carpet accounted for between 4.9% (eutrophication potential) to 11% (energy consumption) of the total impact of the floor/foundations system, and accounted for 0.09% of the mass of the system. In terms of the total impact of the building, carpet contributed between 1.8% (eutrophication potential) to 2% (energy consumption) of the total impact of the building, and only 0.07% of the mass of the Waitakere NOW Home®.

The hydro coat epoxy sealer accounted for between 1.9% (acidification potential) to 4.3% (energy consumption) of the total impact of the floor/foundation system, but only accounted for 0.02% of the mass of the system.

Tiles installed in the bathroom had a minimal contribution to the overall impact of the floor/foundation system and will therefore not be discussed further.

3.3.3.3 Windows

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

Window material	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
Aluminium	10.1	0.8	3,362	1.6	44,207
Glass	3.8	0.5	811	0.3	8,383
Timber	0.04	0.005	26	0.03	1,137
Paint	0.03	0.0005	2.0	0.001	46
Total	14	1.3	4,201	1.9	53,773

Table 7: Environmental impacts of each material in the Waitakere NOW Home® window system

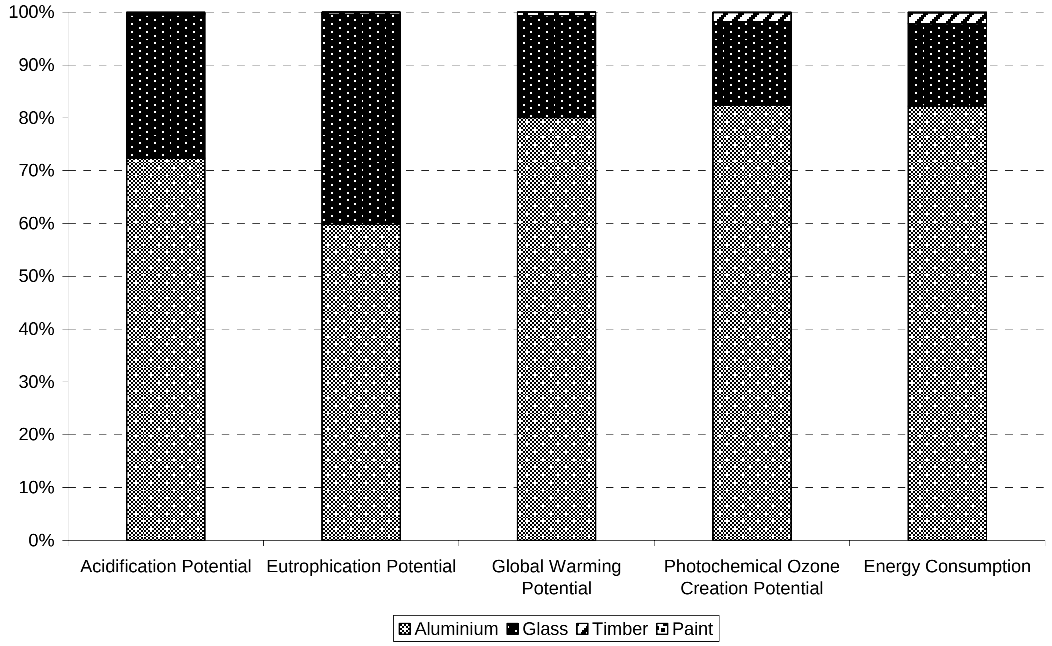

Figure 7: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® window system

The percentage contribution of the windows to the total impact of the building ranged from 14% (energy consumption) to 24% (acidification potential), with a mass contribution of 1% of the Waitakere NOW Home®.

Aluminium accounted for the greatest contribution to all impact categories, ranging from 60% (eutrophication potential) to 82% (photochemical ozone creation potential). Aluminium accounted for 82% of the embodied energy of the windows but only 22% of the mass of the window system, which amounted to 12% of the total embodied energy of the building and less than 1% of the total mass of the Waitakere NOW Home®.

Note that the aluminium window frames will be recycled at the end of life stage of the building. In this section only the initial embodied impact of the window system and its materials are presented, prior to any end of life treatment. At the end of life stage the benefits from the recycling process will be considered and attributed to the end of life stage, which will influence the overall life cycle impact of the building.

Glass was the next largest contributor to the impact categories, accounting for between 16% (photochemical ozone creation potential) and 40% (eutrophication potential) of the total impact of the window system, and 70% of the mass of the window system. The contribution of glass to the total eutrophication potential of the building accounted for 8.4% of the total impact, but only accounted for 0.5% of the mass of the Waitakere NOW Home®. Glass also accounted for 16% and 27% of the embodied energy and acidification potential of the window system respectively.

The environmental impact contributions of timber and paint were insignificant, with minimal contributions to the environmental impacts of the window system and the Waitakere NOW Home®.

3.3.3.4 External walls

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

External wall component	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
External finish	3.6	0.2	973	1.0	37,667
Framing	1.2	0.1	715	0.9	32,165
Insulation	0.7	0.08	307	0.1	4,931
Internal finish	1.5	0.09	327	0.09	6,071
Total	6.9	0.5	2,321	2.2	80,834

Table 8: Environmental impacts of each component in the Waitakere NOW Home® external wall system

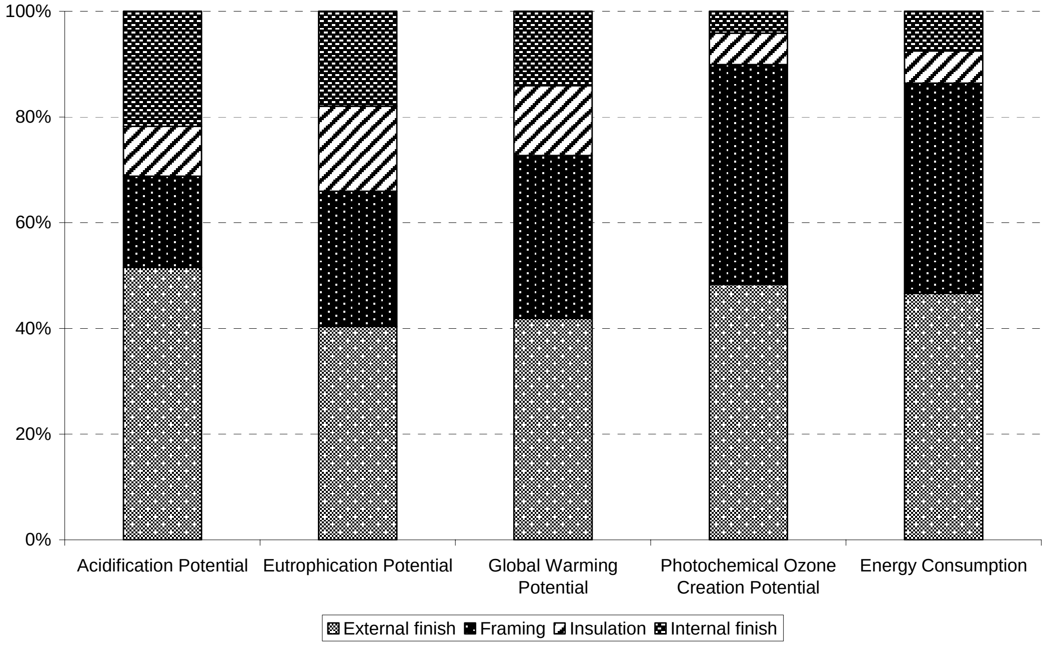

Figure 8: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® external wall system

The contribution of the external wall system to the total impact of the building ranged from 8% (eutrophication potential) to 21% (energy consumption), with a contribution of 4% of the mass of the Waitakere NOW Home®.

The embodied energy of the external wall system accounted for 21% of the total embodied energy of the building. Framing and external finish accounted for the majority of the embodied energy of the external wall system with 40% and 47% respectively, and 35% and 38% of the mass of the external wall system respectively. Timber accounted for a high proportion of the mass of the framing and the external finish with 99% and 94% respectively. The contribution from timber in the framing and external cladding to the embodied energy of the external wall system was 38% and 39% respectively.

Table 9 and Figure 9 present the proportion of non-renewable and renewable energy consumed by each external wall component. A high proportion of the embodied energy of the framing and external finish is attributed to renewable energy, with 91% and 83% respectively. This is largely from the timber within these components and takes into account the energy stored in the timber as a potential energy source[4]. If this was subtracted, the total energy use for timber would be significantly lower, and hence the contribution of renewable energy would be lower. The total timber in the external walls accounted for 70% of the mass of the external wall system, and the renewable energy embodied in all the timber in the external wall system accounted for 74% of the total embodied energy of the external wall system. 24% of the embodied energy of the external wall system is non-renewable.

External wall component	**Non-renewable (MJ)**	**Renewable (MJ)**	**Total (MJ)**
External finish	6,550	31,117	37,667
Framing	2,861	29,304	32,165
Insulation	4,619	312	4,931
Internal finish	5,164	906	6,071
Total	19,195	61,639	80,834

Table 9: Non-renewable and renewable energy consumption of each building component in the wall system of the Waitakere NOW Home®

4The dataset for timber is based on the assumption that timber will be incinerated at its end of life which is common practice Europe. The dataset therefore accounts for the energy stored in the timber. This is shown as renewable energy. This is influences the results in two ways – firstly the embodied energy is relatively high and secondly the contribution of renewable energy for timber is very high.

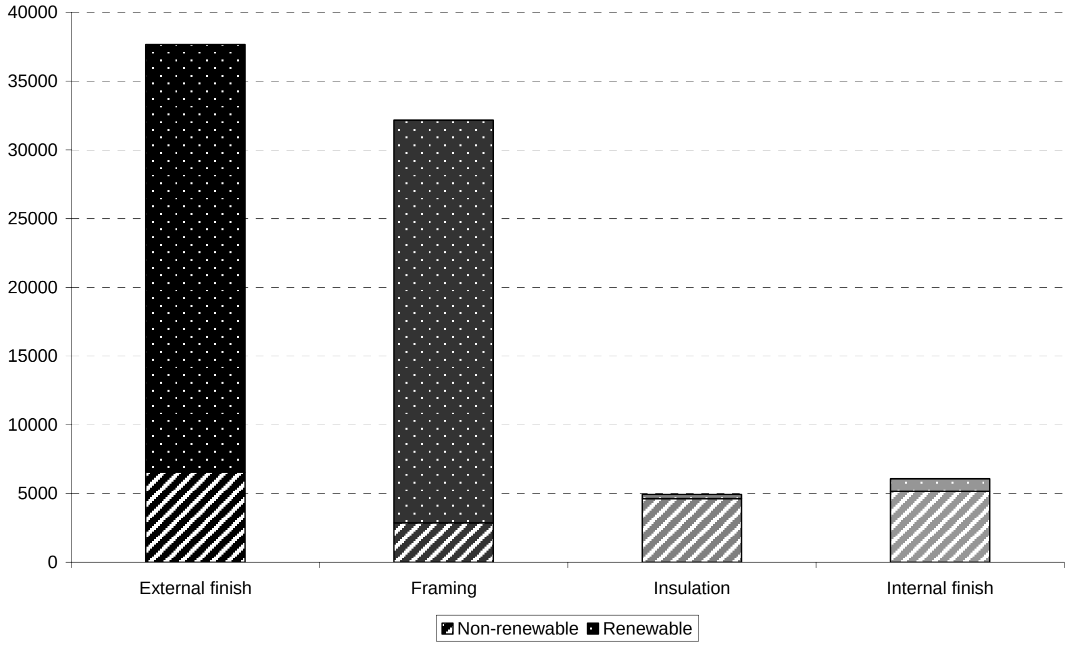

Figure 9: Proportion of total embodied energy of each component in the external wall system of the Waitakere NOW Home®, between non-renewable and renewable energy

It is notable that framing has a large contribution to photochemical ozone creation potential (41%), which is largely attributed to the harvesting process of timber. The contribution of the framing photochemical ozone creation potential to the total building impact is 8.2%, while it accounts for only 1.5% of the mass of the Waitakere NOW Home®. The timber installed for exterior weatherboard cladding accounts for 42% of the total photochemical ozone creation potential of the external wall, and 35% of the mass of the external wall.

The total photochemical ozone creation potential attributed to timber is 84% of the photochemical ozone creation potential of the external wall system, which amounts to 17% of the total photochemical ozone creation potential of the building but only 3% of the mass of the Waitakere NOW Home®.

The exterior finish of the external wall system had the greatest acidification potential, accounting for 52% of the total impact of the external wall system, which is largely attributed to the paint applied to the weatherboard cladding. The exterior paint accounted for 57% of the acidification potential of the exterior finish of the system, and 3% of the mass of the external finish of the system.

Overall, paint contributed 45% to the total acidification potential of the external wall system (including exterior and interior finishes), but only accounted for 1.7% of the mass of the external wall system, which amounted to 5.3% of the total acidification potential of the building and only 0.07% of the mass of the Waitakere NOW Home®.

Glass wool insulation accounted for 6.1% of the total embodied energy of the wall system but only 2.5% of the mass of the wall system, which amounted to 1.3% of the total embodied energy of the building and 0.1% of the mass of the Waitakere NOW Home®.

3.3.3.5 Internal walls

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

Internal wall material	**AP [kg SO2-Equiv.]**	**EP [kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**	**POCP [kg Ethene-Equiv.]**	**Energy [MJ]**
Timber	0.02	0.002	11	0.01	466
Paint	2.1	0.03	137	0.07	3,105
Gypsum board	0.9	0.15	503	0.09	8,419
Framing	1.2	0.1	751	0.9	33,109
Tiles	0.1	0.01	28	0.01	381
Total	4.3	0.3	1,429	1.1	45,480

Table 10: Environmental impacts of each material in the Waitakere NOW Home® internal wall system

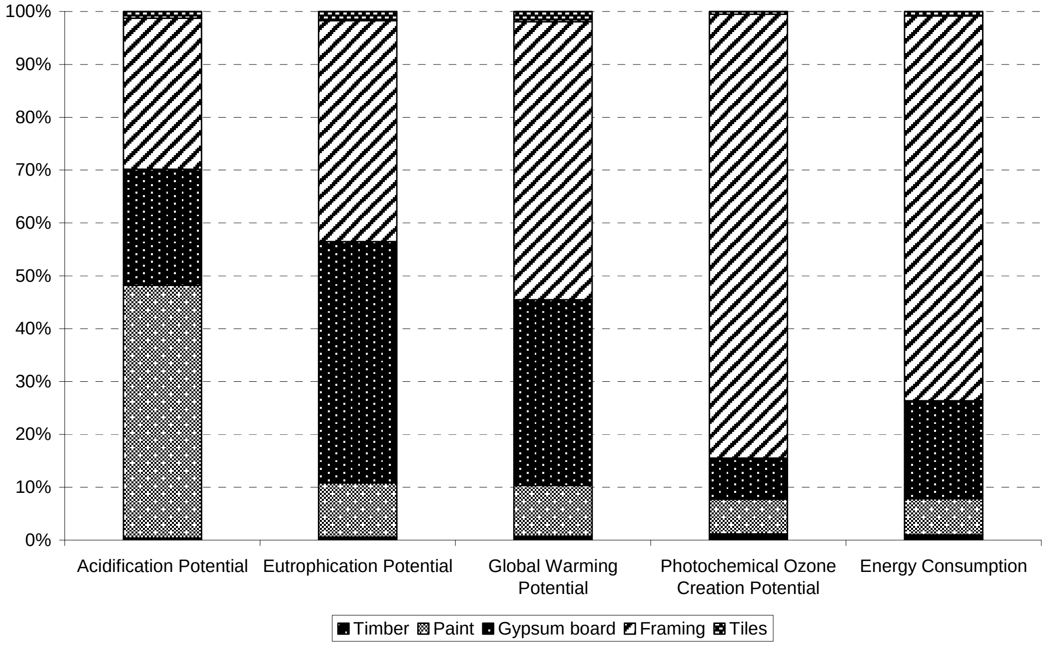

Figure 10: Percentage contribution to environmental impacts of each material in the Waitakere NOW Home® internal wall system

The internal wall system accounted for between 5.2% (eutrophication potential) and 12% (energy consumed) of the total impact of the building, and 3.8% of the mass of the Waitakere NOW Home®.

Framing accounted for the greatest contribution to the photochemical ozone creation potential (82%), energy consumption (73%), and global warming potential (53%) of the internal wall system, and the dominant material in this component was timber.

Table 11 and Figure 11 present the proportion of non-renewable and renewable energy consumed by each internal wall material. A high proportion of the framing embodied energy is from renewable sources (94%), which accounted for 68% of the total embodied energy of the internal wall system. The embodied energy of the framing installed in the internal walls amounted to 8.8% of the embodied energy of the building.

Gypsum board accounted for 19% of the total embodied energy of the internal wall system, of which 86% is from non-renewable energy sources. The embodied energy of gypsum board installed in the internal walls amounts to 2.2% of the total embodied energy of the building.

Internal wall material	Non-renewable (MJ)	Renewable (MJ)	Total (MJ)
Timber	28	437	466
Paint	3,054	51	3,105
Gypsum board	7,240	1,179	8,419
Framing	2,039	31,070	33,109
Tiles	270	111	381
Total	12,632	32,849	45,480

Table 11: Non-renewable and renewable energy consumption of each building material in the internal wall system of the Waitakere NOW Home®

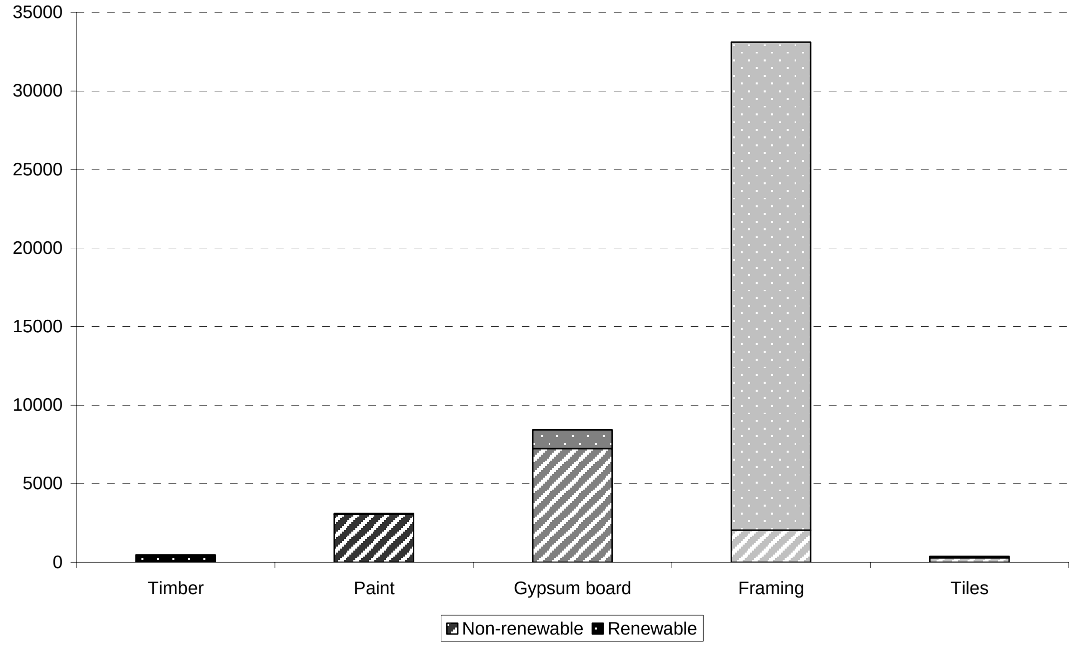

Figure 11: Proportion of total embodied energy of each component in the internal wall system of the Waitakere NOW Home®, between non-renewable and renewable energy

Framing installed in the internal wall system accounted for a high proportion of the photochemical ozone creation potential (82%) of the system. This amounted to 8.2% of the total photochemical ozone creation potential of the building, and 1.5% of the total mass of the Waitakere NOW Home®.

Gypsum board installed in the internal walls accounted for a high proportion of the eutrophication potential (50%) and global warming potential (35%) of the system, but accounted for 55% of the mass of the internal wall system. This amounted to 2.4% and 2.3% of the total impact of the building for both impact categories respectively.

Paint accounted for a high proportion of the acidification potential of the internal wall system (49%), but accounted for 1.3% of the mass of the internal wall system. This amounted to 3.6% of the total acidification potential of the building and 0.05% of the mass of the Waitakere NOW Home®.

3.3.3.6 Ceiling and Roof

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

Ceiling and Roof component	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	POCP [kg Ethene-Equiv.]	Energy [MJ]
Fascia Guttering	0.3	0.03	193	0.04	2,725
Eaves	0.7	0.1	414	0.1	5,854
Roofing	4.2	0.6	1,971	0.7	24,038
Framing	1.6	0.2	954	1.2	41,737
Insulation	1.8	0.2	842	0.4	13,540
Ceiling	2.3	0.2	598	0.1	10,205
Total	11	1.3	4,972	2.6	98,100

Table 12: Environmental impacts of each component in the Waitakere NOW Home® ceiling and roof system

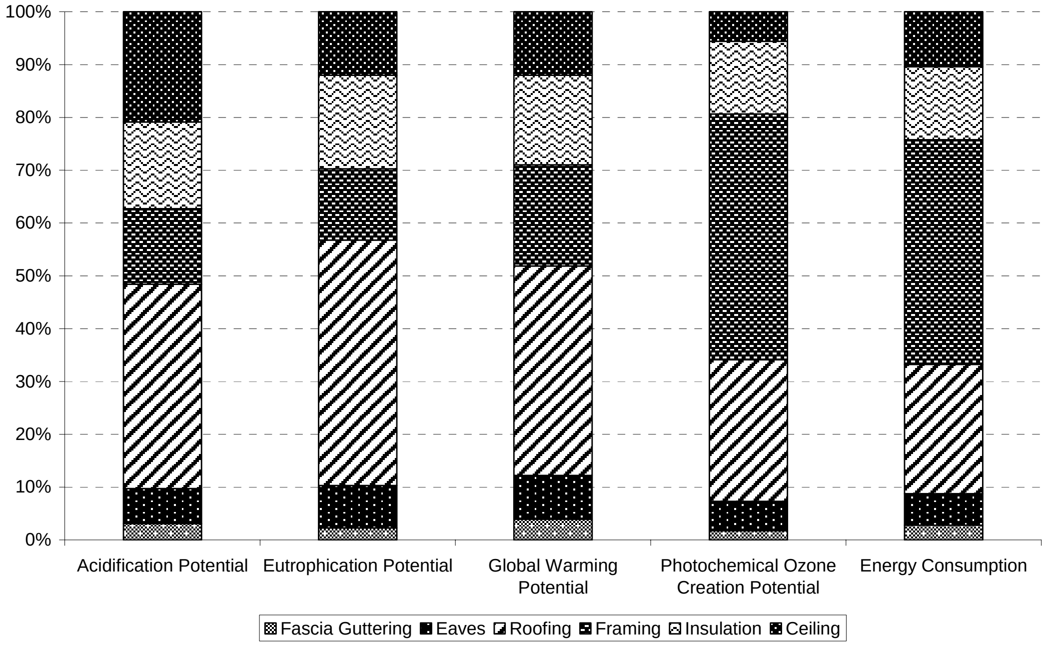

Figure 12: Percentage contribution to environmental impacts of each component in the Waitakere NOW Home® ceiling and roof system

In this analysis, the ceiling and roof system includes roofing, eaves, fascia guttering, framing, insulation, and ceiling.

The contribution of the ceiling and roof system to the total impact of the building ranged from 19% (acidification potential) to 26% (energy consumption), and accounted for 13% of the mass of the Waitakere NOW Home®. The framing and roofing components accounted for the greatest proportion of embodied energy of the ceiling and roof system with 44% and 25% respectively, which amounted to 11% and 6.4% of the total embodied energy of the building respectively.

Roofing materials included concrete tiles, timber battens, and building paper. The majority of the embodied energy of the framing component is attributed to timber. Forty one percent and 50% of the embodied energy of the roofing component is attributed to concrete tiles and timber respectively.

Table 13 and Figure 13 present the distribution between non-renewable and renewable energy consumption for each component in the ceiling and roof system. Ninety four percent of the embodied energy of the framing component is attributed to renewable energy consumption, which is largely from the timber installed for framing. Fifty two percent of the embodied energy of the roofing component is attributed to renewable energy consumption, which is largely due to the timber battens installed under the concrete tiles. Non-renewable energy consumption, which was attributed to concrete tiles, accounted for 40% of the embodied energy of the roofing component.

Renewable energy embodied in the framing timber and timber roofing battens accounted for 51% of the total embodied energy of the ceiling and roof system, and 44% of the total embodied energy of the system was non-renewable energy.

Ceiling and Roof component	Non-renewable (MJ)	Renewable (MJ)	Total (MJ)
Fascia Guttering	2,538	188	2,725
Eaves	4,825	1,029	5,854
Roofing	11,446	12,592	24,038
Framing	2,693	39,043	41,737
Insulation	12,684	857	13,540
Ceiling	9,153	1,052	10,205
Total	43,339	54,760	98,100

Table 13: Non-renewable and renewable energy consumption of each building component in the ceiling and roof system of the Waitakere NOW Home®

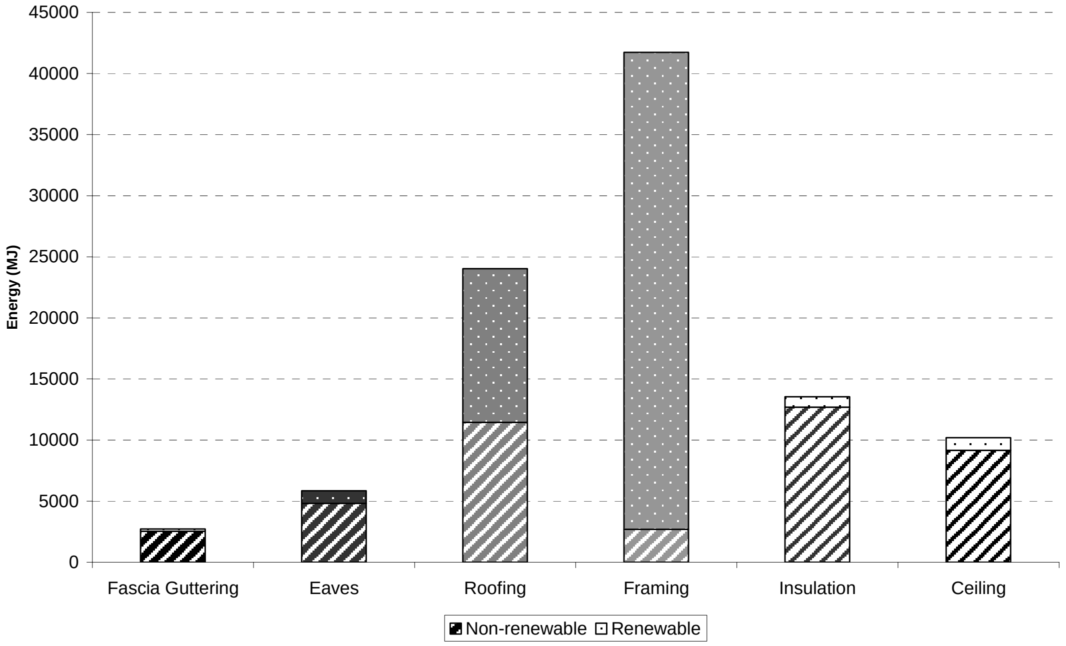

Figure 13: Proportion of total embodied energy of each component in the ceiling and roof system of the Waitakere NOW Home®, between non-renewable and renewable energy

It is notable that framing accounted for a high proportion of the photochemical ozone creation potential of the ceiling and roof system (46%), accountied for only 15% of the mass of the system, which amounts to 10% of the total photochemical ozone creation potential of the building and 1.9% of the mass of the Waitakere NOW Home®.

The roofing component accounted for a high proportion of the eutrophication potential (46%) of the ceiling and roof system. Concrete tiles accounted for the majority of the eutrophication potential of the roofing component and accounted for 38% of the impact of the ceiling and roof system. The contribution of the roofing component to the total eutrophication potential of the building is 9.7% and roofing tiles 8%. The roofing component accounted for 66% of the total mass of the ceiling and roof system and the roofing tiles accounted for 93% of the mass of the roofing component. Concrete tiles were the third greatest material mass in the Waitakere NOW Home®, accounting for 8% of the total mass of the building.

The roofing component also accounted for a high proportion of the global warming potential and acidification potential of the ceiling and roof system (40% and 38% respectively). However, 33% and 32% of the global warming potential and acidification potential of the system is attributed to concrete tiles respectively, which amounted to 7.6% and 6.1% of the total global warming potential and acidification potential of the building respectively.
The glass wool insulation accounted for 14% of the embodied energy of the ceiling and roof system with a mass contribution of 2.2% to the system, which amounted to 3.6% of the total embodied energy of the building and 0.3% of the mass of the Waitakere NOW Home®.
The ceiling component accounted for 11% of the embodied energy of the ceiling and roof system. The ceiling materials included gypsum board, paint, and steel nail-up battens. Gypsum

board accounted for 63% of the embodied energy of the ceiling, and 92% of the ceiling mass, which amounted to 6.5% of the embodied energy of the system, and 12% of the mass of the system. Steel nail-up battens accounted for 17% of the embodied energy of the ceiling component, and only 6.6% of the mass of the ceiling. The ceiling component had a relatively large contribution to the acidification potential of the ceiling and roof system, accounting for 21% of the impact. Fifty nine percent of the acidification potential of the ceiling component is attributed to paint, which accounted for 1.8% of the ceiling mass, amounting to 12% and 2.3% of the acidification potential of the ceiling and roof system and building respectively.

3.3.3.7 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 around 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 2.8% (global warming potential) to 15% (photochemical ozone creation potential) of the total impact. Copper piping and Valsir 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 4.9% 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 by decreasing the lifetime to 50 years, which reflected 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 was to identify whether the difference in lifetime influences the proportion of impact contributed by each life cycle stage of the building.

The main aim was to identify whether the proportion of the combined embodied impact of the construction and maintenance stages decreased in relation to the operational impact as the building life increased.

Table 14 and Figure 14 present the contribution to each impact category of the life cycle stages for 50- and 100-years. 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.

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	71	71	8.4	8.4	23,189	23,189	13	13	399,427	399,427
Maintenance	47	125	1.9	6.5	6,765	22,763	2.9	10.2	134,571	426,677
Operation	193	386	6.2	12.5	38,766	77,531	6	12	936,862	1,873,724
End of life	5	-3	1.9	1.9	916	-629	1.0	0.4	-12,932	-51,130
Total	315	578	18	29	69,636	122,855	23	36	1,457,927	2,648,699

Table 14: Life cycle environmental impacts of the Waitakere NOW Home® with a lifetime of 50 and 100 years

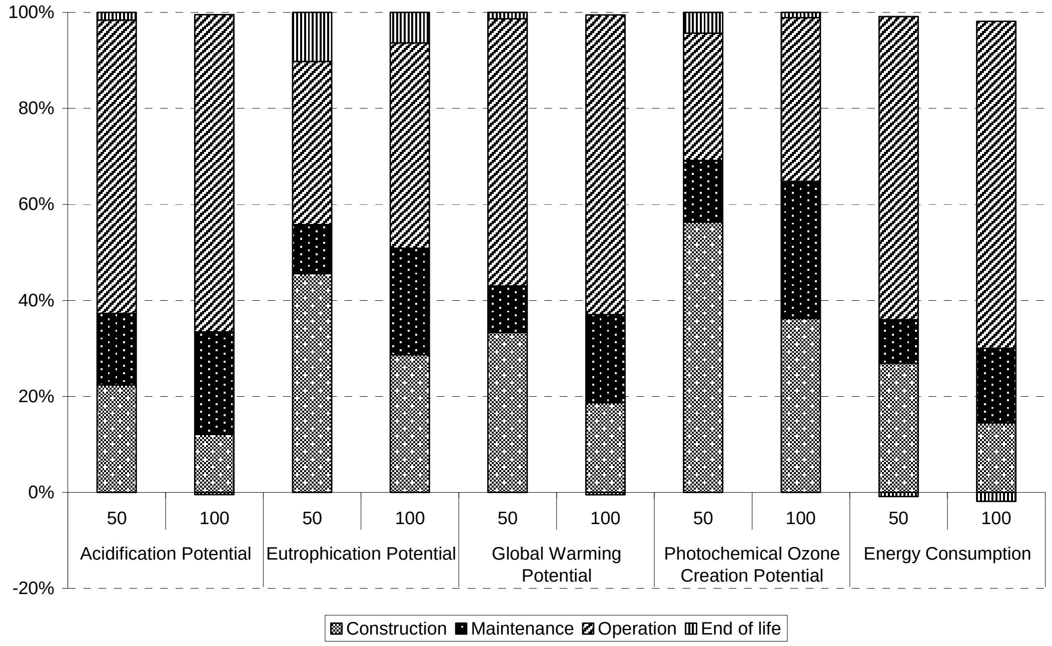

Figure 14: Percentage contribution to life cycle environmental impacts of the Waitakere NOW Home® with a lifetime of 50 and 100 years

Figure 14 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 contribution from maintenance to the embodied energy of the life cycle increases from 9.2% for 50 years to 16% for 100 years, and the contribution to the global warming potential of the life cycle increases from 10% for 50 years to 19% for 100 years. Photochemical ozone creation potential has the greatest increase, from 13% to 29% in the 50- and 100-year lifetime scenarios respectively.

However the total embodied impact of all materials installed in the building over the entire lifetime, which included construction and maintenance related materials, decreased from 43% to 37% of the global warming potential and from 37% to 31% of the embodied energy, for the 50- and 100-year scenarios respectively. 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 increased from 64% in the 50-year scenario to 71% in the 100-year scenario.

The proportion of the end of life impact for all categories decreased as the lifetime extended from 50 to 100 years, and for acidification potential, global warming potential, and embodied energy the impact became negative, indicating a positive impact. This is attributed to the recycling of the aluminium window frames, which outweighed the impact from the other end of life processes such as transport of waste materials and processing within the landfill. The positive impact increased as the life was extended because of a greater quantity of aluminium installed and recycled over the longer life span of the building.

Note that even though the impact was calculated for the end of life phase, the benefits were shared over the whole life cycle impact of the building. In effect it simply reduced the total life cycle impact of the building by a certain amount.

3.3.4.2 System maintenance analysis

The contribution of the maintenance stage to the life cycle impacts ranged between 9.2% (energy consumption) to 15% (acidification potential) in the 50-year lifetime scenario. In the 100-year lifetime scenario the maintenance related impacts ranged from 16% (energy consumption) to 29% (photochemical ozone creation potential) of the total impact of the building.

Table 15 and Figure 15 present the contribution of each maintained system to each impact category for the 50 and 100 year lifetime scenarios.

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	12.3	0.8	1.7	2,663	5,896	0.8	1.7	49,126	108,892
External walls	17	38	0.3	0.9	1,333	3,886	0.8	2.8	33,968	110,649
Internals walls	11	25	0.2	0.6	848	2,346	0.4	1.0	18,524	49,041
Windows	4	21.2	0.3	2.0	1,058	6,316	0.5	2.8	13,644	81,035
Doors	2.8	6.4	0.1	0.1	219	591	0.1	0.4	5,637	17,291
Ceiling and Roof	7	20	0.1	0.9	610	3,562	0.3	1.3	12,848	56,361
Integrated Water Systems	0.03	0.09	0.003	0.009	15	46	0.02	0.02	555	1,701
Total	47	123	1.9	6.3	6,746	22,644	2.9	10.0	134,302	424,972

Table 15: Environmental impacts of each maintained building component of the Waitakere NOW Home® for 50 and 100 year lifetimes

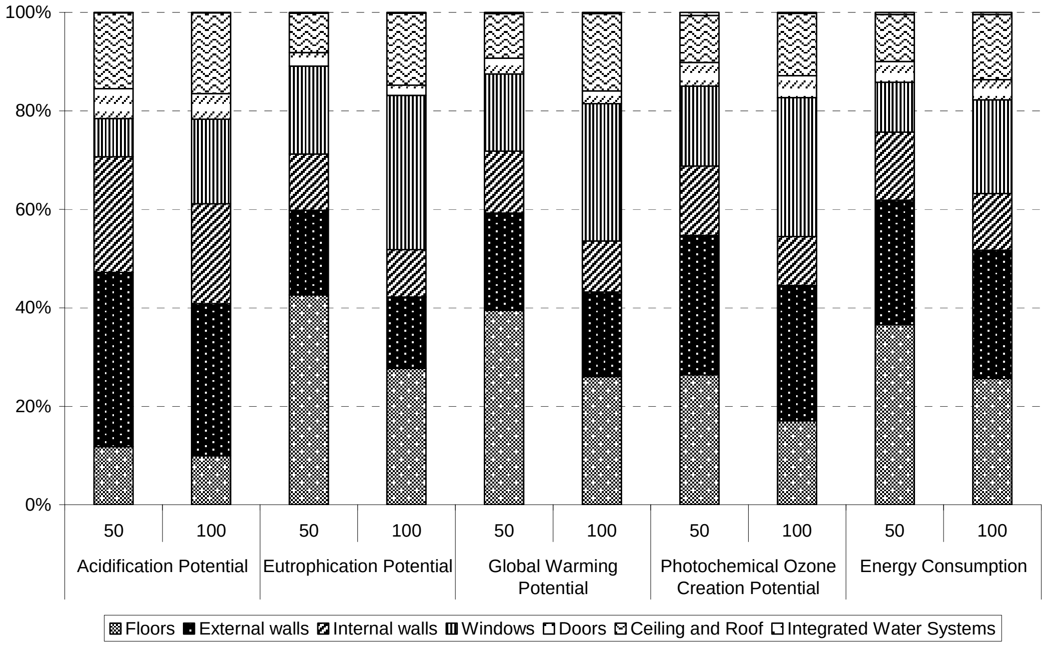

Figure 15: Percentage contribution to environmental impacts of each maintained component of the Waitakere NOW Home® for 50- and 100-year lifetimes

It is notable that the external wall system has a large contribution to acidification potential in both lifetime scenarios. The external wall system accounts for 35% and 31% of the acidification potential in the 50- and 100-year scenarios respectively. This is due largely to repainting; for example, in the 50-year lifetime scenario paint accounted for 97% of the acidification potential of the external wall system. The internal wall system also accounted for a high proportion of acidification potential and this was also largely due to repainting.

The external wall system also accounted for a high proportion of the total maintenance related embodied energy, with 24% and 25% of the impact in the 50- and 100-year lifetime scenarios respectively. This was largely due to replacement of timber weatherboards and reapplication of paint, which accounted for 44% and 48% respectively of the total impact of the system in the 100-year scenario.

The floor component accounted for a high proportion of the maintenance related embodied energy, global warming potential, and eutrophication potential in the 50- and 100-year lifetime scenarios. The floor component accounted for around 38% and 26% of the maintenance related embodied energy and global warming potential in the 50- and 100-year scenarios respectively, and around 43% and 28% of the maintenance related eutrophication potential in the 50- and 100-year scenarios respectively. Around 64% and 36% of the impact of these impact categories was attributed to re-carpeting and re-application of hydro coat epoxy sealer for the concrete slab respectively.

Maintenance of the window system accounted for a high proportion of the eutrophication potential of the maintenance stage, and increased from 18% to 31% in the 50- and 100-year lifetime scenarios respectively. Aluminium accounted for a high proportion of the maintenance related impact of the window system, accounting for 80% and 81% of the embodied energy of the system in the 50- and 100-year lifetime scenarios respectively. The maintenance related impact of the window system becomes more dominant as the lifetime extends from 50 to 100 years, due to an increased mass of aluminium from 46kg to 274kg.

Glass also accounted for 39% 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 eave and roofing components are maintained in the 100-year scenario, which increased the impact of the ceiling and roof system for all categories as the lifetime was extended from 50 to 100 years. For example, the embodied global warming potential of the ceiling and roof system increased from 9% to 16% as the lifetime increased from 50 to 100 years. The maintenance of the eave and roofing components involves replacing the fibre cement and PVC joiners in the eaves, and the concrete tiles and timber battens in the roof.

Maintenance of the ceiling component accounted for a relatively high proportion of the acidification potential of the maintenance stage, accounting for around 14% of the total maintenance related impact in both the 50- and 100-year lifetime scenarios. Paint applied to the ceiling accounted 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. 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.

3.4 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, together 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 63-71% to each of these categories.

The percentage contribution from operation for global warming potential and acidification potential is similar to that of energy consumption, as 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 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 years one and two respectively. Hot water accounted for around 70% and 77% of the total HL+HW energy consumption in years one and two respectively.

The construction and maintenance stages were the next biggest contributors, both with similar contributions. The photochemical ozone creation potential of the construction stage was relatively high (36%) and this was largely due to the built-in timber, which accounted for a low proportion of the mass of the Waitakere NOW Home® (7.5%) but a relatively high proportion of the photochemical ozone creation potential of the building (36%). However, the absolute photochemical ozone creation potential impact of the timber was not very high. It only appears high in comparison to the very low impacts contributed by the other life cycle stages.

The maintenance stage had a relatively high acidification potential (22%) which was from the large quantity of paint applied through maintenance, throughout the 100-year life of the building.
The end of life stage had the smallest contribution to the life cycle impact, and in some impact categories the impact was negative. This was a reflection of the benefits from recycling the aluminium window frames. The impact categories where there was the greatest influence were acidification potential, global warming potential, and energy consumption.

This is because the initial embodied impact of aluminium is mainly related to these categories, therefore recycling the material will counteract the same impact categories.
For example, the end of life global warming potential is -629kg CO_2 equivalent, which translated as the amount of unreleased CO_2 from recycling the aluminium. This provided an output of recycled aluminium which avoided the need to produce the material from virgin aluminium with high embodied impacts.

Note that, even though the end of life impact becomes negative for some categories, in effect this merely decreases the overall life cycle impact of the building by a certain amount.

Eutrophication Potential and Photochemical Ozone Creation Potential were still positive impacts because the impact from transporting and processing the materials in landfill outweighs the benefits from recycling the aluminium.

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 contributed the most to the environmental impacts of a home.
- To 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.
- To provide a benchmark for the development of further NOW Homes®.

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

3.5.1 Environmental hotspots

The floor/foundation system of the Waitakere NOW Home® accounted for the greatest proportion of most of the environmental impacts (acidification potential, eutrophication potential, and global warming potential).

The external wall system accounted for a high proportion of the photochemical ozone creation potential and embodied energy of the building. This was largely due to the high content of timber installed for exterior cladding and framing. However, in reality, this impact was relatively low. It appears high in relation to other materials, because they have very low impacts.

Timber appears to have a relatively high embodied energy, with the majority of this from renewable energy. This is due to the modelling applied in the dataset. For consistency, the European datasets were used for all materials, including timber. However, the dataset was based on the assumption that timber will be incinerated at end of life, and therefore accounts for the energy stored in the timber. This is shown as renewable energy. This influenced the results in two ways: firstly the embodied energy is relatively high and, secondly, the contribution of renewable energy for timber is very high.

The window system accounted for a relatively significant proportion of the total embodied energy of the building (14%), but a minimal proportion of the mass of the building. Aluminium had the greatest embodied energy to mass ratio of all materials installed in the Waitakere NOW Home®. However, aluminium window framing was recycled in this study and this resulted in a significant reduction in the end of life impact and the overall life cycle impact for each category.

Paint accounted for a high proportion of the acidification potential of the Waitakere NOW Home®. However, the paint that was modelled in the GaBi software was not the exact paint that was applied to the Waitakere NOW Home®, therefore the impacts may differ. However, the difference in impact would not be too significant, as the manufacturing processes are similar, and the same trends would be seen in terms of distribution of impact between impact categories.

The concrete roofing tiles and gypsum board accounted for a high proportion of the embodied energy of the building, which 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, but it was assumed the tank would not require maintenance throughout the life of the Waitakere NOW Home®. The tank also meant that water was efficiently used.

The end of life stage accounted for the smallest contribution to overall impact, and for acidification potential, global warming potential, and energy consumption the impact was negative. This was a reflection of the benefits from recycling the aluminium window framing at the end of life of the building.

3.5.2 Maintenance

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

Aluminium and timber had a smaller mass, but higher embodied energy. However, the embodied energy in timber is largely from renewable energy sources (biomass) and aluminium window frames were recycled in this study.

3.5.3 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 63-71% 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 years 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 contributors 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.

3.5.4 Benchmark

This is a ‘one off’ study, 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/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.

3.5.5 Limitations of research

The use of European data for the building materials is a limitation of the study. However, the results still provided indicative results that allow a meaningful hotspot analysis.

3.5.6 Future research

The most important next step would be to update the data once New Zealand life cycle inventory data is available. With regard to future work on new homes, it would also be interesting to 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 63 to 71% 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

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

and will therefore shift the focus to materials for two reasons. Research on building systems also needs to be a priority.

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

The relatively high embodied energy for timber indicates potential energy source at the end of life that requires further research for New Zealand with regard to the utilisation of timber from construction/demolition waste as an energy source.

4 Papakowhai Renovation homes

In the Papakowhai Renovation project, nine existing houses in Papakowhai, Porirua, were renovated to "…identify the best (most cost effective and easy to implement) packages and combinations of renovation options to significantly improve the HSS High Standard of Sustainability® of the homes..." (Burgess *et al*., 2008). The nine houses were all built in the 1970s.

Two of the nine Papakowhai Renovation homes (identified as House 2 and House 10) are evaluated in this report, and represent 'basic renovations' and 'high renovations' respectively. The two homes were chosen because the performance of the homes as a result of the renovations was very positive.

The water and energy usage, as well as the temperature in the master bedroom and living room, were monitored in these houses both before and after renovation.

This analysis of the two renovated houses should be viewed alongside other Papakowhai Renovation home reports (e.g., Burgess *et al*., 2008), as this report only examines the renovation materials, with a focus on embodied energy and energy use.

4.1 House 2

House 2 (Burgess *et al*., 2008) is a two storey house constructed in 1970, with a metal tile roof, predominantly timber windows, and a mixture of weatherboard and sheet cladding. The house has four bedrooms and a living area of 140m^2. Prior to renovation, the house had fibreglass Batts in the ceiling, and wall insulation in the master bedroom only. The house was heated with a wood burner and occasionally with oil column heaters. The house had an electric, low pressure hot water cylinder.

The cost of renovations for House 2 was approximately $2,120, and consisted of:

- Insulation of the hot water cylinder and pipes;
- Insulation under-floor and mid-floor;
- Insulation in the ceiling;
- Plumbing check;
- Installation of energy efficient light bulbs;
- Installation of a worm farm;
- Installation of a new cat door;
- Installation of a new smoke alarm.

4.2 House 10

House 10 (Burgess *et al*., 2008) was built in the early 1970s, and had had little maintenance since. This house is a two storey house with four bedrooms. It has a concrete slab floor, concrete walls, and the roof is concrete tiles. Prior to the renovation, house 10 had timber windows, and was heated with an old wood burner and oil column heaters. The floor was not insulated, the walls were insulated downstairs only, and the ceiling had old, patchy glass fibre insulation.

The cost of renovation for House 10 was approximately $74,070 (including the approximate cost of labour for work done by the homeowner) and consisted of:

- Ceiling insulation;
- Under-floor and mid-floor insulation;
- Wall insulation and new plasterboard;
- Installation of a solar water system with an additional hot water cylinder;
- Installation of double glazed windows with aluminium frames;
- Installation of a wood burner with wetback;
- Installation of energy efficient light bulbs;
- Installation of a worm farm;
- Garage door draught-proofed;
- Plumbing checked and leak fixed;
- Installation of extractor fans.

4.3 Goal and scope definition

4.3.1 Goal

The goals of this LCA study were:

- To find the environmental hot spots of the Papakowhai Renovation homes in order to identify the systems that contributed the most to the environmental impacts of a home.
- To compare the embodied energy in the renovations of the Papakowhai Renovation homes (cradle to gate) with the heating operational energy of the homes post-renovation.
- To provide a benchmark for further renovation projects.

4.3.2 Scope and System Boundaries

The analysis of the two Papakowhai Renovation homes included the renovation of the homes only. The homes themselves were excluded from the analysis. Thus, the analysis included the life cycle phases: renovation (including waste of materials during renovation); the transport of new materials to the building and waste from the building; and the disposal/recycling of the materials at the end of the building's life. The use phase has been excluded, and the reduction in impacts caused by a reduced reticulated energy demand post-renovation has not been included in the analysis of the environmental impacts of the renovations.

The system boundaries applied in this study were ‘cradle to grave’, which meant that all impacts from extracting raw materials, processing and manufacturing of the product, the transport, and the disposal/recycling of the product after its useful life were considered. Upstream processes, such as the production of diesel used in transport as well as the emissions during diesel combustion, have been taken into account, including all related environmental impacts. The system boundary of the study is shown in Figure 16.

Houses 2 and House 10 are assumed to have a useful life of 60 years[6] and, being built around the 1970s, have a remaining useful life of approximately 20 years. Although the renovations will most likely extend the life of the building, particularly in the case of House 10 where the renovations were extensive, no lifespan extension has been included in the study, but qualitative discussions on the effects of an extended lifespan have been made in section 4.8 of this report. The extended lifespan scenario provides insight into the advantages and disadvantages of renovating to extend the life of a house as opposed to building a new house.

The choice to exclude an extended lifespan was made in order to retain comparability in the results between the renovated house and the house if no renovations had occurred. An extended life span would result in maintenance requirements for non-renovated parts of the house, which would need to be accounted for in order to accurately compare a renovated and non renovated house over the extra life time. In addition, if the renovations were to extend the life of the house an additional 30 years (for example) relative to the non-renovated house then, in order to retain comparability, the non-renovated house option would require a replacement house to be built for the additional 30 years.

This report aims to identify the environmental hotspots and embodied energy of the renovations. However, this analysis would be obscured by the maintenance and building of a replacement house if an extended life span was included. Thus, although unrealistic, for the purposes of this analysis the renovated houses are assumed to have the same life span as prior to renovation, i.e., a further 20 years.

Maintenance of the renovation materials has been excluded as no maintenance is expected to occur during the remaining life span of the houses (20 years).

In this report, the distinction between ‘renovation’ and ‘maintenance’ has not been made. For example, the replacement of old ceiling insulation is most likely ‘maintenance’ rather than ‘renovation’, whereas the addition of insulation materials in locations that did not previously have insulation is more likely to be a ‘renovation’. In addition, ‘refurbishment’ may have been carried out on the houses to update them, not because of necessity. However, for the purposes of this report, all renovation work is regarded as a ‘renovation’.

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[6] ***P. Hancock, Energysmart, Personal Communication, 15 May 2008***

For the embodied energy calculation, all energy input from the renovations, including transport of the materials from the production site to the house, and the disposal/recycling of the renovation materials at the end of the building life were included. No disposal of existing household materials during renovation was included (for example the old timber windows taken from House 10), as these materials would have been disposed of at the end of the building life if the renovations had not taken place, and are therefore not additional burdens caused by the renovations.

Waste of renovation materials (e.g., from damages, cut-offs, etc) have been included in the study. As waste materials need to be produced, transported to the house and disposed of, the environmental impacts of the waste materials are identical to those of the materials used in the renovations. Thus, waste materials have been included with non-wasted materials in the results, and are not analysed separately. 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.

Fuel and electricity consumption, together with their upstream processes, were taken into account. The provision of infrastructure and capital goods, such as roads, trucks for transport, machinery, etc., was not considered. Accidental damage and misuse were excluded from the analysis. The impacts of installing the materials have been excluded from the analysis.

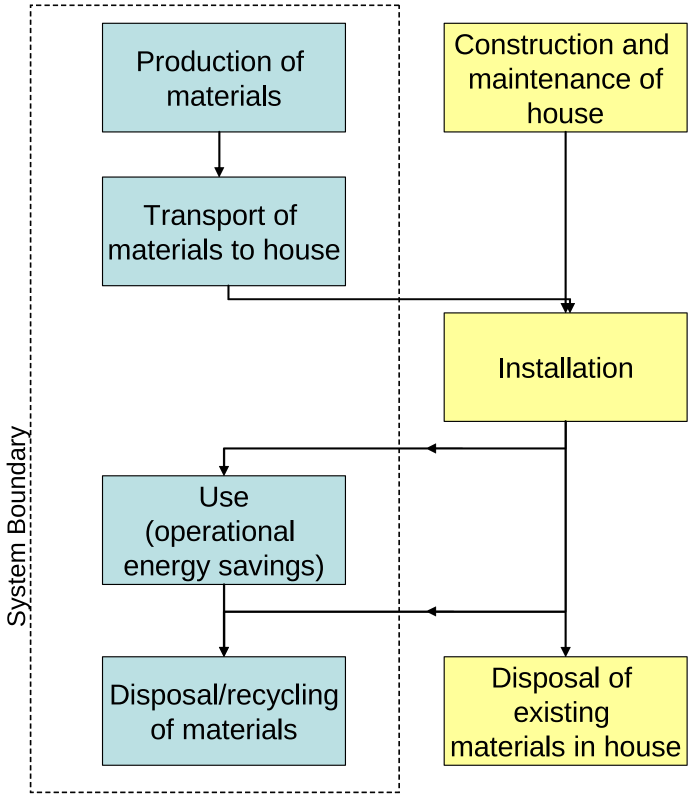

Figure 16: System boundary of the renovated homes

4.3.3 Functional Unit

The functional unit is one renovation package, to last the remainder of the use phase of the building (20 years for both houses), in New Zealand. All results will be presented in terms of this functional unit. As the two houses had different renovations, the functional unit is different for each house.

4.3.4 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.

4.3.4.1 Input/output data

Accurate information on the quantity of material used was available from invoices for work carried out. Information regarding the quantity of glass wool used in the renovations was accurate, as the area used was provided in the invoices, and the thickness and density of the different types of Batts available from the Pink Batts® website and other sources. For other materials and systems (e.g., plastics and solar hot water heater) where material and component specifics were not available, assumptions were based on ecoinvent v2.0 data (Ecoinvent, 2008), and literature sources. These data are therefore ‘general’ or ‘standard’ data, rather than data specific to the renovation materials used.

4.3.4.2 Life cycle inventory data

New Zealand specific life cycle inventory data for building materials is currently not available. The life cycle inventory data used in this study is therefore 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 and as well as the emissions related to energy use and production. Capital equipment is excluded[7].

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

The documentation describes the production process, applied boundary conditions, allocation rules etc. for each product. The database is compliant with the ISO Standards 14040 and 14044.

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

4.4 Inventory analysis

The inventory analysis provides detailed material and energy balances over the lifecycle 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 Lifecycle Impact Assessment. The inventory is structured according to the lifecycle stages of the renovations: production of materials, transport of materials to house, and disposal at end of life.

4.4.1 House 2

The quantities of materials used in the renovations of House 2 are displayed in Table 16.

Renovation	Component	Material	Thickness (mm)	Density (kg/m3)	Area (m2)	Weight (Kg)	Comments/source
Ceiling insulation	Pink®Batts® R2.6	Glass wool	110	18.5	109	221.8	(Tasman Insulation NZ, 2004)
Underfloor and mid-floor insulation	Pink®Batts® R2.0	Glass wool	70	10	86	60.2	(Tasman Insulation NZ, 2004)
		Aluminium	0.01	2700	86	2.3	Thickness and density assumed Area from (Tasman Insulation NZ, 2004)
	Polythene sheet	polyethylene	0.125	920	54	6.2	Thickness and density assumed
Hot water cylinder and pipe insulation	Foam pipe	Polyurethane	5m (length)	110	0.0006	0.3	Length and density assumed
	Pink batts	Glass wool	50	10	3.6	1.8	(Tasman Insulation NZ, 2004)
	Pink batts	Aluminium	0.01	2700	3.8	0.1	Aluminium overlaps glass wool and therefore has a greater area[8]

Table 16: Material inventory data for House 2

The worm farm, cat door, extractor fan and fire alarm have been excluded from the assessment, as these items are not related, or have a small relation, to the energy performance of the building. In addition, the environmental impacts of these items are assumed to be negligible compared with the impacts of the other materials in the building.

The energy efficient lights were also excluded from the assessment, as lights are replaced many times throughout the life of a building, and the difference in the environmental impacts in the manufacture of an energy efficient light bulb and a standard light bulb is assumed to be negligible.

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[8] ***P. Hancock, Energysmart, Personal Communication, 15 May 2008***

Table 17 displays the transport means and distances assumed for House 2. These figures are estimated, and include only the transportation from the production site to the house, and from the house to the landfill.

Item	Production location	Means of transport	Distance (km)	Weight transported (kg)	Comments
Glass wool	Auckland	Truck 20-26 tonne capacity	658	286.2	Assumed distances and production locations.
All other materials	Local	Truck 12-14 tonne capacity	40	6.5	
Disposal	To Landfill	Truck 20-26 tonne capacity	10	292.7	

Table 17:Transportation and disposal inventory data for House 2

The distance and means of transport for each material is a rough estimate only. However, transport and disposal have only a small contribution to the total impacts of the renovation, and an increase in the accuracy of these figures would not significantly affect the results.

4.4.2 House 10

The quantities of materials used in the renovations of House 10 are displayed in Table 18.

Renovation	Component	Material	Thickness (mm)	Density (kg/m3)	Area (m2)	Weight (Kg)	Comments/ source
Ceiling insulation inc. garage	Pink batts R2.6	Glass wool	110	18.5	210	427.35	(Tasman Insulation NZ, 2004)
	Pink batts R2.0	Glass wool	70	10	24	16.8	(Tasman Insulation NZ, 2004)
		Aluminium	0.01	2700	24	0.65	Thickness and density assumed
Underfloor and mid-floor insulation	Pink batts R2.0	Glass wool	70	10	81.2	56.84	(Tasman Insulation NZ, 2004)
		Aluminium	0.01	2700	81.2	2.19	Thickness and density assumed
	Pink batts R3.9	Glass wool	155	9.7	12.2	22.9	Thickness based on pink batts R3.6 (Tasman Insulation NZ, 2004)
	Polythene sheet	Polyethylene	0.125	920	64	7.36	Thickness and density assumed
Wall insulation	Pink batts R2.4	Glass wool	94	10	139.8	131.4	Thickness based on pink batts R2.2 (Tasman Insulation NZ, 2004)
	Pink batts R1.2	Glass wool	40	12	7	3.36	Thickness based on pink batts R1.0 (Tasman Insulation NZ, 2004)

Renovation	Component	Material	Thickness (mm)	Density (kg/m3)	Area (m2)	Weight (Kg)	Comments/ source
	Plasterboard	Gypsum plasterboard	10	7.35/m^2	140	1029	To replace plasterboard removed during insulation
Wood burner and wetback	Steel components of burner	Steel	4	7850	1.8	57.5	Assumed data
	Glass tiles on burner	Glass	8	3000	1.1	26.1	
	Wetback & pipes	Copper	2	8930	0.3	5.7	
Solar water system, HWC and pipes	Hot Water Cylinder and steel in solar water system	Steel	4	7850		21.6	Data of 4.14kg from ecoinvent v2.0 (Ecoinvent, 2008) for solar water system + 17.5kg HWC
	Pipes	Copper	2	8930	3.5	64.5	Data of 2.82kg from ecoinvent v2.0 (Ecoinvent, 2008) for solar water system + 61.7kg pipes
		Polyurethane	50m (length)	110	0.013	3.2	
	Solar water system components	Glass				0.91	Data from ecoinvent v2.0 (Ecoinvent, 2008)
		Silicon				0.06	
		Aluminium				3.93	
		Corrugated board				3.68	
		Rubber				0.06	
		Propylene glycol				1.01	
		Solder				0.06	

Renovation	Component	Material	Thickness (mm)	Density (kg/m3)	Area (m2)	Weight (Kg)	Comments/ source
		Glass wool				2.43	
Windows	Glass panes	Glass	8	3000	23.95	574.8	Area of glass from Fisher Windows[9], thickness and density assumed
	Aluminium frames	Aluminium		1.28kg/m	148.81m	190.5	Kilogram per metre of perimeter based on BRANZ window

Table 18: Material inventory data for House 10

The same assumptions as for House 2 have been made with regard to the worm farm, extractor fan, garage, draught-proofing, plumbing work, fire alarm, and energy efficient lights.

The quantity of aluminium used in the windows was calculated from the perimeter of the windows in the house, including any framing through the centre of a window. Windows that opened were counted twice to account for the additional aluminium framing used. This length was then multiplied by a 'density per metre' of 1.28 kg/m based on BRANZ data[10].

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[9] ***S. Hillis, Fisher Windows, Personal Communication, 11 June 2008***

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

Table 19 displays the transport means and distances assumed for House 10. These figures are estimated, and include only the transportation from the production site to the house and from the house to the landfill/recycling facility.

Item	Production location	Means of transport	Distance (km)	Weight transported (kg)	Comment
Glass wool, plasterboard, Aluminium for windows	Auckland	Truck 20-26 tonne capacity	658	1881.0	Assumed distances and production locations.
Solar water system	Australia	Bulk commodity carrier ship and truck with 20-26 tonne capacity	2500km by ship 50km by truck	101.5	
All other materials	Local	Truck 12-14 tonne capacity	40	671.4	
Disposal	To Landfill/ Recycling	Truck 20-26 tonne capacity	10	2653.9	

Table 19: Transportation and disposal inventory data for House 10

The distance and means of transport for each of the materials is a rough estimate only. However, transportation and disposal have only a small contribution to the total impacts of the renovation, and an increase in the accuracy of these figures would not significantly affect the results.

Glass wool was modelled using glass specifically made for glass wool rather than using some recycled glass, as is done in New Zealand. This is explained in Section 4.7.

The windows in the House 10 renovations contained a large quantity of aluminium, and it is assumed this is recycled at the end of life. The recycling of aluminium retains the material in use, and eliminates the need to produce new aluminium. The recycling can therefore be regarded as saving primary resources. Aluminium recycling involves the impacts associated with the process (transport, processing, etc), but also involves the ‘negative impacts’ associated with the avoided production of virgin material. The recycling of aluminium therefore reduces the overall environmental impacts of House 10.

4.5 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)
- 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 years and 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).

4.5.1 House 2

Table 20 and Figure 17 show the life cycle environmental impacts of the House 2 renovations. The results are broken down into each of the materials used, the transport of materials to the house, and the disposal of materials at the end of the useful life of the house.

The production of glass wool in Pink Batts has the largest contribution to the environmental impacts of the renovations. As the addition of glass wool to the house made up 97% of the total materials added on a mass basis, the predominance of glass wool on the environmental impacts of the P02 renovations is expected.

The largest quantity of glass wool was added to the ceiling of the house. The ceiling is therefore the system of the House2 renovations with the largest environmental impacts.

Although it is not possible to extract the effect of individual interventions from the complete renovation package (Burgess *et al*. 2008), it is likely that the ceiling is also the renovation responsible for the greatest energy savings to House 2.

P02	**AP [kg SO2-Equiv.]**	**EP [kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**	**POCP [kg Ethene-Equiv.]**	**Energy [MJ]**
Aluminium foil	0.129	0.005	27	0.0131	441
Glass wool	1.711	0.205	796	0.3512	12130
Polyethylene sheet	0.033	0.003	18	0.0083	544
Polyurethane foam	0.006	0.002	2	0.0005	31
Transportation	0.088	0.015	12	0.0078	174
Disposal	0.026	0.003	6	0.0040	53
Total	1.993	0.232	861	0.3849	13373

Table 20: Life cycle environmental impacts of the House 2 renovations

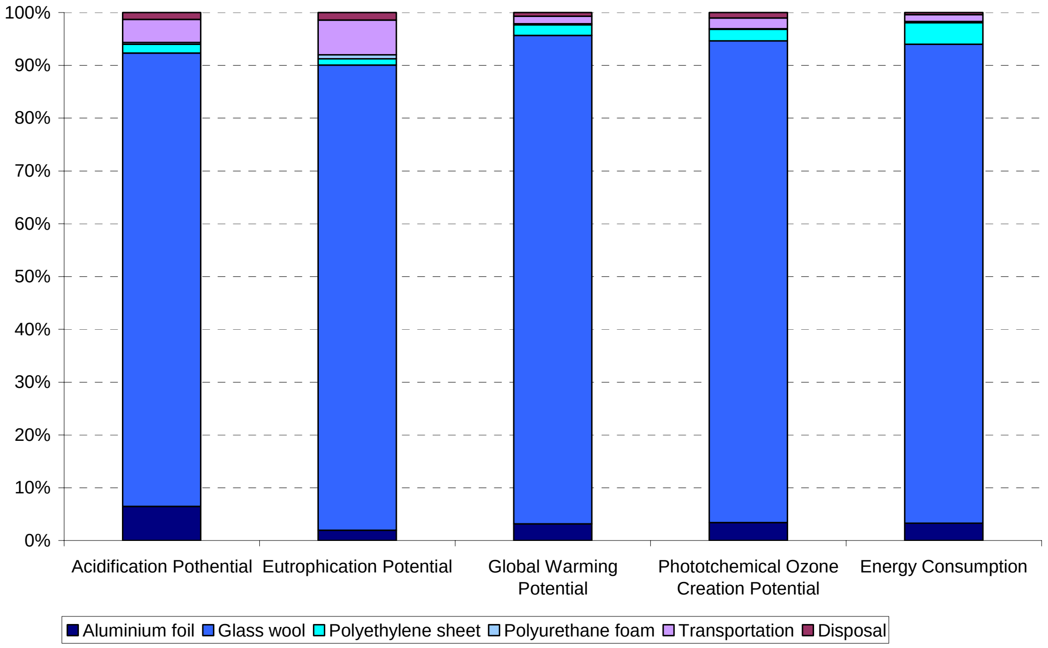

Figure 17: Life cycle environmental impacts of the House 2 renovations

4.5.2 House 10

Table 21 and Figure 18 show the life cycle environmental impacts of the House 10 renovations. The results are broken down into each of the materials used, the transportation of materials to the house, and the disposal/recycling of materials at the end of the useful life of the house.

The materials that contributed most significantly to the environmental impacts of the House 10 renovations are glass, aluminium, glass wool, copper and steel.

Aluminium has high environmental impacts on a mass basis, contributing only 7% to the mass of the materials added to the house, but contributing up to 15% to the environmental impacts. Aluminium contributes to 14% of the global warming potential and 15% of the energy consumption of the House 10 renovations.

Conversely, glass contributes 23% to the total mass of materials in the House 10 renovation, but only contributes 11% to the global warming impact and 12% to the energy consumption of the renovation. Glass contributes most strongly to the photochemical ozone creation potential (25%) of the renovation.

The main contributors to the global warming potential and energy consumption of the renovation are aluminium and the glass wool in Pink Batts, both of which contribute to these environmental impacts disproportionately to their mass.

As for the House 10 renovations, the transport of materials to the house and the disposal of the materials in a landfill only have a small contribution to the total environmental impacts of the renovation (between 3% and 8%).

The percentage contribution of each material to global warming potential is similar to that of energy consumption. These two categories are closely related, as non-renewable energy use is a main contributor to global warming. This is because most non-renewable energy is fossil fuel based and therefore contributes strongly to the global warming potential.

House 10	**AP [kg SO2-Equiv.]**	**EP [kg Phosphate-Equiv.]**	**GWP [kg CO2-Equiv.]**	**POCP [kg Ethene-Equiv.]**	**Energy [MJ]**
Glass	2.7	0.21	462	0.49	7270
Aluminium (with recycling)	2.0	0.06	567	0.30	9076
Copper	1.5	0.10	337	0.11	5384
Glass wool	4.0	0.50	1863	0.82	28246
Plasterboard	0.4	0.07	226	0.04	3778
Steel	2.0	0.94	394	0.12	5396
Other materials	0.2	0.03	48	0.02	1144
Transport	0.6	0.11	85	0.05	1182
Disposal	0.3	0.05	69	0.04	666
Total	13.8	2.07	4052	1.99	62142

Table 21: Life cycle environmental impacts of the House 10 renovations

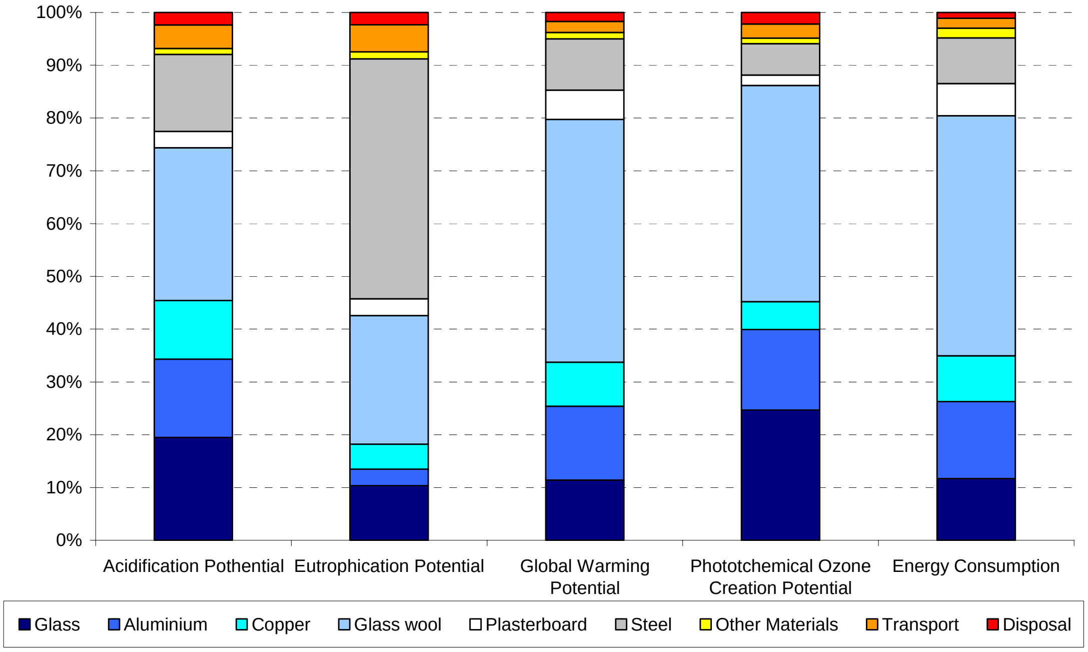

Figure 18: Life cycle environmental impacts of the House 10 renovations

The windows have high environmental impacts in the House10 renovations. Both the glass and the aluminium contribute significantly to the environmental impacts of the renovations, and both are more predominantly present in the windows than they are in other systems. Glass wool also has a high impact, and was added in the largest quantities to the walls of the house (135kg). As for the House 2 renovations, it is not possible to allocate specific savings to specific interventions. Therefore, the extent to which the renovated window system (for instance) contributed to the total energy savings of the house is not known.

4.6 Embodied and operational energy

The embodied energy of the renovations includes all energy used by the renovations, including the production of materials, the transport of materials to the house, and the disposal of the materials at the end of the useful life of the house.

The operational energy for heating includes only the energy used for heating the house, and excludes other operational energy use such as for lighting and cooking, etc. The operational energy for heating the renovated houses is taken from the interim monitoring results (Burgess *et al.* 2008) and has been scaled up to include the total heating operational energy use that would occur over 20 years (the remaining useful life of the houses). The heating operational energy use is based monitoring over five months, and is presented in Table 22.

House	**Heating operational energy post renovation (5 months)(MJ)**	**Heating operational energy post renovation (20 years) (MJ)**
House 2	655.6	31466.7
House 10	491.7	23600.0

Table 22: Heating operational energy over five months and 20 years, post-renovation, for House 2 and House 10.

The operational energy use for heating over 20 years is compared with the embodied energy of the renovations in Table 23, Figure 19 and Figure 20.

Renovations	**Embodied Energy (MJ)**	**Heating operational Energy use (20 years) (MJ)**
House 2	13 373	31467
House 10	62 142	23600

Table 23: Embodied energy and operational energy use for heating for the renovations to House 2 and House 10

The embodied energy of the House 2 renovation is smaller than the operational energy use for heating of the renovated house over 20 years.

House 10 had more extensive renovations than House 2, and therefore has a higher embodied energy. The embodied energy of House 10 is significantly larger than the operational energy use for heating over 20 years. This means than, from an energy perspective, there is a greater need to justify the renovations of House 10 than of House 2.

In this study the remaining useful lifespan of the houses was estimated to be 20 years. If however a longer life cycle had been used, the operational energy for heating of the houses would be greater. The extended life scenario is discussed in section 4.8 of this report.

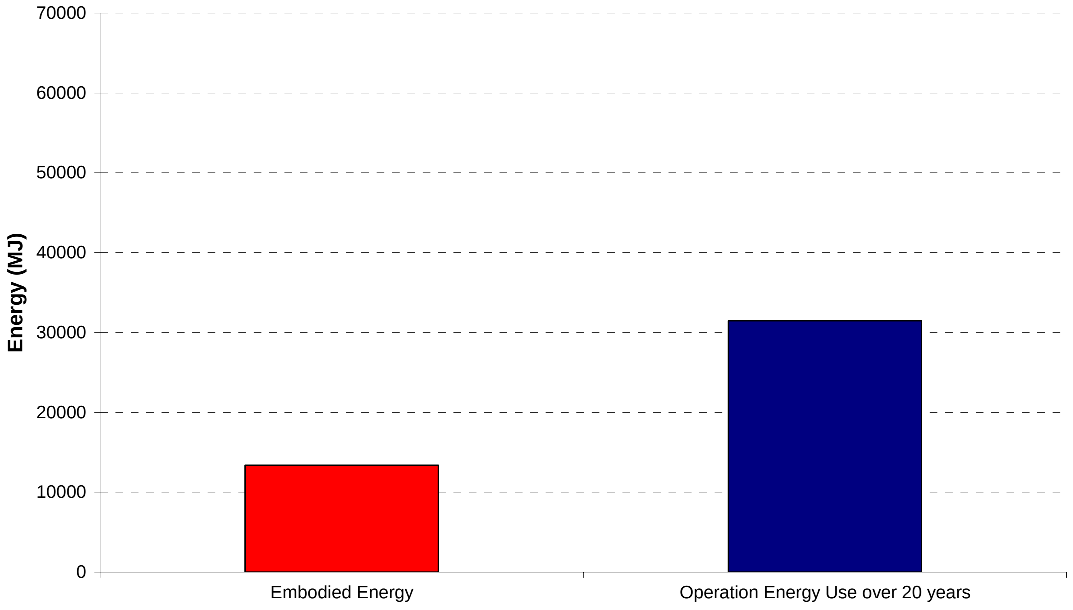

Figure 19: Embodied energy and operational energy use for heating for the renovations to House 2

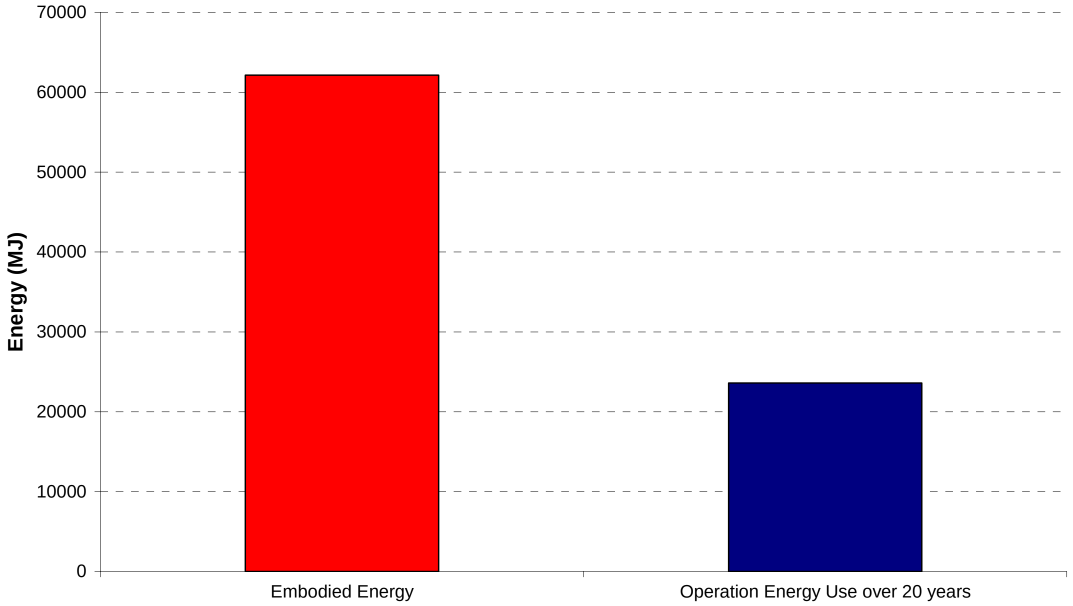

Figure 20: Embodied energy and operational energy use for heating for the renovations to House 10

4.7 Hotspot analysis

The hotspots in the renovations are the processes/materials with the greatest contributions to the environmental impacts of the renovations. Changes in the amounts/burdens of these materials will result in the greatest changes to the overall impacts of the renovations.

In the House 2 renovation, the main environmental impacts are from the glass-wool in the insulation materials. Glass wool is the dominant contributor to *all* environmental impacts in the P02 house, due to the large amount of insulation materials installed house in relation to the other materials used.

In the House 10 renovation, the main contributors to the environmental impacts are glass wool, glass, and aluminium. Steel contributes strongly to the eutrophication potential of the House 10 renovations and steel and copper both have contributions disproportionately large in comparison to their contributions by mass.

Contribution Material	**Acidification**	**Eutrophication**	**Global warming**	**Photochemical Ozone Creation**	**Energy Consumption**
Glass	20%	10%	11%	25%	12%
Aluminium	15%	3%	14%	15%	15%
Glass wool	29%	24%	46%	41%	45%

Table 24: Contribution of 'hotspot' materials to the House 10 renovation

Factors relating to these materials need to be taken into account when interpreting the results of this study.

4.7.2 Aluminium

The production of aluminium was modelled using an existing GaBi 4.3 dataset for European aluminium. The main impacts from aluminium arise from electricity use in aluminium production, as aluminium production is an energy intensive process. As the New Zealand power grid mix is mainly based on ‘renewable’ forms of energy, the environmental impacts of aluminium (particularly global warming) are likely to be lower for New Zealand produced aluminium. The global warming impact would be most strongly reduced because the use of fossil fuels is a high contributor to global warming.

4.7.3 Glass wool

The glass wool was modelled using glass specifically made for glass wool. This was done because data for this process is readily available in the GaBi 4.3 software. In the New Zealand situation, however, glass wool is made partially from recycled glass previously used for other purposes. The environmental impacts of New Zealand glass wool are therefore likely to be lower than those modelled here. The environmental impacts of the recycled glass wool will be from:

- The collection of waste glass.
- The re melting of waste glass and processing into glass wool.
- A proportion of the impacts of primary glass production process based on, for example, the economic value of waste glass

The re melting of waste glass and processing into glass wool is a relatively energy intensive process. Therefore, the use of recycled glass instead of primary glass to make glass wool would not significantly change the environmental impacts of the study.

4.8 Extended life span scenario analysis

As discussed earlier, it is likely the renovations will extend the life span of the houses, particularly in the case of House 10, where the renovations were extensive. If the renovations extend the life span of the existing house, the requirement of a new replacement house is delayed. The section presents a qualitative analysis of whether it is better from an environmental and energy perspective to renovate an existing home, or build a new one.

For this analysis, the Waitakere NOW Home® is compared with the House 10 renovations, over 30 years. It should be noted that these homes are two specific examples and do not represent the generic, or average, New Zealand home. In addition, the houses are not the same design, operate in different regions, and house a varying number of occupants (the Waitakere NOW Home® is a 3-bedroom house and House 10 has 4 bedrooms). Thus, although numerical analysis has been done on the extended lifespan scenario, the uncertainties are sufficient that only qualitative indications can be drawn from this analysis.

It is assumed that the renovations extend the life span of House 10 by 30 years, to a total remaining life span of 50 years.

Two scenarios are analysed:

Scenario 1: House 10 is renovated, which extends the life span of the house by 30 years

Scenario 2: House 10 is not renovated, and another house is built to house the occupants for the remaining 30 years

The Waitakere NOW Home® has an expected life span of 100 years. Therefore, 30% (30 years) of the lifetime of the Waitakere NOW Home® is sufficient to replace the House 10 for 30 years, had the house not been renovated. The embodied energy and environmental impacts of the Waitakere NOW Home® have been scaled back for this analysis, to correspond to the 30-year extended life span of House 10.

The 30-year extended life span of House 10 would require maintenance of the non-renovated parts of the house. Calculations of the maintenance requirements of House 10 are not possible, as data for the non-renovated materials in the house is not available. Therefore, the maintenance requirements of the house over 30 years are assumed to be equal to the maintenance requirements for 30 years of the Waitakere NOW Home®.

The operational energy of the homes has been excluded, as the operational energy data of the two homes is not comparable. The maintenance on the non-renovated materials in House 10 over 20 years has not been included for both scenarios, as the home was expected to last a further 20 years had the renovation not been carried out.

Table 25 compares the 30-year extended life of House 10 with a home if no renovations had been carried out, including maintenance of the renovated home and replacement of the non-renovated home with a new home (Waitakere NOW Home®).

Impact	**Scenario 1:** **House 10 renovated house over 50 years**	**Scenario 2:** **Un-renovated scenario (House 10 un-renovated house over 20 years + Waitakere NOW Home® over 30 years)**
Acidification Potential	51.3	57.6
Eutrophication Potential	4.02	4.8
Global Warming Potential	10,881	13,597
Photochemical Ozone Creation Potential	4.99	7.2
Embodied Energy	190,145	232,493

Table 25: Comparison of 30-year extended life House 10 vs un-renovated equivalent

The results of the scenario analysis indicate it is better to renovate an existing home than build a new one from an environmental and energy perspective.

Maintenance is assumed to be identical for both scenarios, however in Scenario 1 (House 10 renovated house), maintenance has a greater contribution to the impacts analysed than in Scenario 2 (not renovated, with replacement house). This is because the impacts of construction and disposal of the House 10 relate only to the renovated materials, whereas maintenance occurs for all materials in the house. Maintenance of House 1 renovated over the extended life span may be greater than what is assumed here, as the old House 10 would probably have more maintenance requirements than the new house build in Scenario 2.

4.9 Interpretation

Glass wool is the predominant contributor to the environmental impacts of the House 2 renovations, and is a significant contributor to the impacts of the House 10 renovation as well. This is due to the large quantity of glass wool installed in both the houses.

In House 10, the installation of aluminium framed, double glazed windows had a significant contribution to the total environmental impacts. This was in part due to the large quantity of windows installed (a total weight of 695kg), but also due to the aluminium window frames, which have an environmental impact disproportionately large compared to their contribution by mass.

The operational energy use for heating of the houses post-renovation is dependent on the energy efficiency of the house, the type of heating in place, the number of occupants, and the indoor temperature desired by the occupants, amongst other factors. It should be noted that the operational energy data is based on five months of monitoring only, and the extrapolation of this data to a 20 year period introduces large uncertainties, as the 5-month data may not be representative of the long term, or average, energy use of the Papakowhai Renovation homes. The embodied energy of the renovations was smaller than the heating operational energy over 20 years for House 2, but greater for House 10. This is primarily due to the extent of the renovations for each house. The renovations to House 10 are likely to extend the lifespan of the house, which would increase the operational energy for heating over its remaining life, and reduce the difference between embodied energy and operational energy for heating.

Another factor to consider is that the LCA study does not take the increase in comfort into account. A true comparison would have to be based on the theoretical energy requirements prior to the renovation to bring the indoor temperature to the same level following renovation. However, this was beyond the scope of the study, which was to be based on existing data from the Papakowhai project.

The addition of aluminium-framed windows in the House 10 renovations had a significant impact on the environmental and embodied energy performance of the House 10 renovation. Although it is not possible in this study to attribute operational energy savings to specific renovation measures, it is possible that similar operational energy savings could be obtained by renovating House 10 using more environmentally friendly window systems, for instance, timber-framed windows.

The embodied energy of the Waitakere NOW Home® (the energy input from cradle to gate) is 399,427 MJ. This is almost thirty times the energy input of the House 2 renovation (13,373MJ), and over six times the energy input of the House 10 renovation (62,142MJ). The energy input of the renovations is therefore significantly less than the energy required to construct a total house.

4.10 Summary and conclusions

In this study, two of the nine Papakowhai Renovation homes (House 2 and House 10), which present ‘basic renovations’ and ‘high renovations’ respectively, were analysed using Life Cycle Assessment. The goals of the LCA study were:

- To identify the environmental hot spots of the renovation projects in order to identify the systems which contribute the most to the environmental impacts of a home.
- To compare the embodied energy in the renovations of the Papakowhai Renovation homes (cradle to gate) with the operational energy use for heating after the renovations.
- To provide a benchmark for further renovation projects.

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

4.10.1 Environmental hotspots

Glass wool is the predominant contributor to the environmental impacts of the House 2 renovations, and is a significant contributor to the impacts of the House 10 renovation as well. This is due to the large quantity of glass wool installed in both the houses.

In the House 2 renovation, the main environmental impacts are from the glass wool in the insulation materials. Glass wool is the dominant contributor to *all* environmental impacts in House 2, due to the large amount of insulation materials installed in relation to other materials used.

In the House 10 renovation, the main contributors to the environmental impacts are glass wool, glass, and aluminium. Steel contributes strongly to the eutrophication potential of the House 10 renovation, and steel and copper both have contributions disproportionately large in comparison to their contributions by mass.

4.10.2 Embodied versus operational energy

The embodied energy of the renovations was smaller than the heating operational energy over 20 years for House 2, but greater for House 10. This is primarily due to the extent of the renovations for each house. However, the LCA study does not take the increased comfort level into account. A true comparison would have to be based on the theoretical energy requirements prior to the renovation to bring the indoor temperature to the same level as it would be following renovation.

An analysis of the operational energy *savings* with the embodied energy of the two Papakowhai Renovation homes would have been beneficial, as this would have given insight into the relationship between the extent and type of renovation that yields the greatest energy savings. This analysis was not possible, however, as the average indoor temperature was different before and after renovation, and the difference in operational energy savings before and after renovation was therefore not a meaningful result. It is therefore not possible to draw conclusions regarding the relationship between the extent of the renovations and the resultant energy savings from a life cycle point of view.

4.10.3 Benchmark

A comparison of House 10 with an extended lifespan and the Waitakere NOW Home® indicates that, from an environmental and energy perspective, it is better to renovate an existing house and therefore extend its lifespan rather than build a new house. The uncertainties in this analysis are high, as House 10 and Waitakere NOW Home® are two specific examples, and do not represent the average or generic New Zealand home. This result therefore needs to be confirmed using analysis from a wider sample of New Zealand homes.

4.10.4 Limitations of research

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

4.10.5 Future research

The most important next step would be to update the data once the New Zealand life cycle inventory data is available. With regard to future work on retrofitting homes, it would also be interesting to model different materials. This information could then be used in the development of future retrofit projects.

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6 Appendix One: 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;
- 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 undertaking LCA.

Four different phases can be distinguished.

8) *Goal and Scope Definition:* The goal and scope of the LCA study are clearly defined in relation to the intended application.
9) *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.
10) *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.
11) *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 21. In practice, LCA involves a series of iterations as its scope is redefined on the basis of insights gained throughout the study.

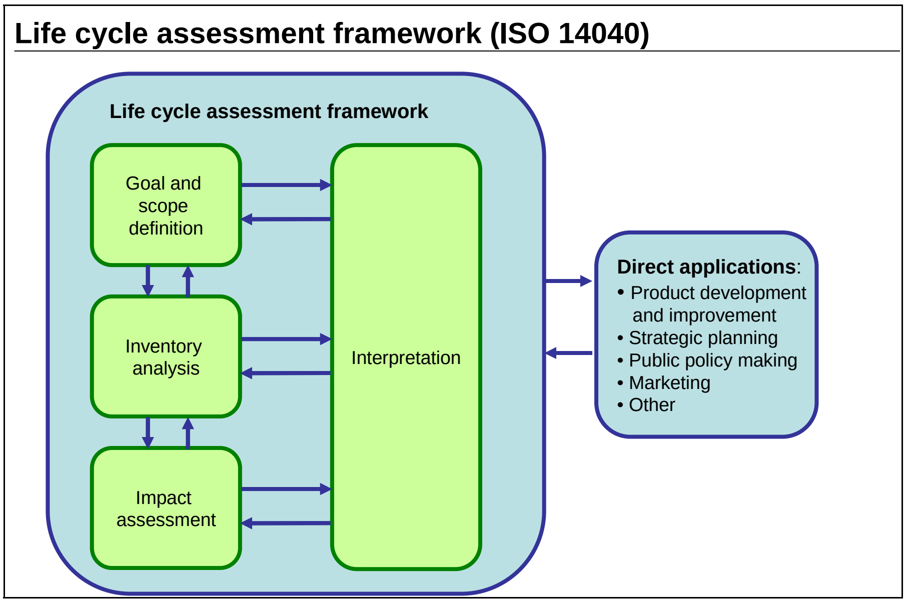

Figure 21: LCA framework (ISO 14040)

Impact Assessment Categories

The environmental impacts of the Waitakere NOW Home® and the two Papakowhai Renovation homes were 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;
- Photochemical ozone creation (POCP), expressed in kg C_2H_2 equivalents.

The Waitakere NOW Home® and Papakowhai Renovation homes were also analysed for non renewable energy use.

Description of the Impact Categories

- **Global warming potential 100 Years (GWHOUSE 100)** ***i***s caused mainly by CO2 and CH4 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***)* is the most well-known effect of acidifying emissions, acid rain, and 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 soil conditions.
- **Eutrophication potential (EP)** refers to an increase in biomass production due to the 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 occur in the generation, transmission, and distribution of energy. For example, the provision of 1 MJ of electricity from natural gas requires 2.6 MJ of primary energy.

Furthermore, there are four toxicity categories, i.e., 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.

7 Appendix Two: Data tables excl. maintenance

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
PE damp proof membrane	900
Polycarbonate	1,200
Polypropylene	946
Polystyrene	16
PVC	1,380
Sand	1,800
Steel	7,800
Timber (dry)	420

Table 26: Density of building materials

Building component	**Material**	**Quantity (kg)**
Foundation		86,696
Hard fill		34,197
	Polyethylene DPC	33
	Gravel	26,280
	Sand	7,884
Slab insulation		457
	Polystyrene	22
	Hardiflex flat sheet	435
Concrete slab and footings		52,042
	Concrete	51,090
	Steel wire	564
	Timber boxing	355
	Flashings	33
Walls		8,907
External walls		4,714
Framing		1,632
	Timber frame	1,608
	Steel bracing	2
	Dampcourse bitumac	22
Insulation	Fibre glass Pink Batts	116
External finish		1,777
	Paint	54
	Weatherboards	1,627
	Additional trim	42
	Soakers	34
	Building paper	20
Internal finish		1,189
	Gypsum board	1,146
	Finishing timber	16
	Paint	27
Internal walls		4,194

Building component	**Material**	**Quantity (kg)**
Framing		1,707
	Timber frame	1,705
	Steel bracing	2
Finish		2,487
	Gypsum board	2,293
	Tiles (kitchen and bathroom)	116
	Finishing timber	24
	Paint	54
Floors		130
	Hydrocoat epoxy sealer	20
	Carpet	81
	Tiles (bathroom)	29
Roof		14,415
Eaves		338
	Hardisoffit flat sheet	290
	Timber	46
	PVC	2
Framing		2,151
	Timber	2,142
	Steel (galv)	9
Roofing		9,511
	Concrete tile	8,858
	Building paper	37
	Timber battens	616
Ceiling		2,223
	Paint	35
	Gypsum board	1,743
	Steel (galv)	126
Insulation	Fibre glass Pink Batts	320
Fascia guttering		192

Building component	Material	Quantity (kg)
	Colorsteel	192
Windows		847
	Flashings	9
	Aluminium frame	183
	Glass	596
	Timber reveal	59
	Paint	0.8
Doors		366
Interior doors		302
	Hollow core timber	245
	Paint	14
	Timber	30
	Copper flashing	13
Garage door		64
	Colorsteel	47
	Timber	16
	Paint	0.9
Integrated Water Systems		268
	Copper tubing	11
	Polypropylene	8
	Polyethylene rainwater tank	250
Pergola		168
	Polycarbonate	7
	Timber	71
	Glulam timber	81
	Steel (galv)	8
Total		111,797

Table 27: Material quantities in each building component

Building elements (kg)	NOW Home®
Floor/foundations	86,826
External walls	4,714
Internal walls and partitions	4,194
Ceiling and Roof	14,415
Windows	847
Doors	302
Integrated Water Systems	268
Other	232
Total	111,797

Table 28: Total weight of building components (excluding maintenance)

Materials (kg)	**NOW Home®**
Aluminium	191
Malthoid	22
Building paper	56
Carpet	81
Concrete	51,090
Concrete tiles	8,858
Copper	23
Epoxy resin	20
Fibre cement	725
Glass	596
Glulam	81
Gravel	26,280
Gypsum board	5,182
Insulation fibre glass	436
Paint	186
PE damp proof membrane	33
Polycarbonate	7
Polyethylene	250
Polypropylene	8
Polystyrene	22
PVC	2
Sand	7,884
Steel	1,017
Tiles	145
Timber	8,601
Total	111,797

Table 29: Total weight of materials (excluding maintenance)

8 Appendix Three: Data tables for maintenance

			Quantity (kg)	
Building component	**Material**	**Lifetime (yrs)**	**50 years**	**100 years**
Walls			**2,001**	**9,304**
External wall			**1,138**	**5,207**
External finish			**706**	**3,154**
	Paint	8	284	621
	Weatherboards	40	407	2,441
	Additional trim	40	10	62
	Building paper	40	5	30
Internal finish			**432**	**2,054**
	Gypsum board	40	287	1,719
	Finishing timber	40	4	24
	Paint	8	142	311
Internal wall			**863**	**4,097**
Lining and finish			**863**	**4,097**
	Gypsum board	40	573	3,440
	Finishing timber	40	6	36
	Paint	8	284	621
Floors			**448**	**997**
	Carpet	10	325	731
	Hydrocoat epoxy resin	7	123	266
Roof			**667**	**9,913**
Eaves			**0**	**292**
	Hardisoffit flat sheet	50	0	290
	PVC	50	0	2
Roofing			**0**	**6,316**
	Concrete tile	60	0	5,905
	Timber	60	0	411
Fascia guttering	Colorsteel	40	**48**	**288**
Ceiling			**619**	**3,016**

	Paint	8	184	403
	Gypsum board	40	436	2,614
Windows			**216**	**1,278**
	Flashing	40	2	13
	Aluminium frame	40	46	274
	Glass	40	149	894
	Timber reveal	40	15	88
	Paint	8	4	9
Doors			**142**	**574**
	Hollow core timber	40	61	368
	Paint	8	74	161
	Timber	40	8	46
Integrated Water Systems	Polypropylene	25	**8**	**23**
TOTAL			**3,481**	**22,088**

Table 30: Weight of materials installed for maintenance for 50 and 100 year lifetimes

9 Appendix Four: Estimated lifetimes of materials

	Material	Adalberth	Jaques as quoted by Mithraratne	Jaques,	Rawlinsons	Fay, as quoted by Mithraratne (Australia)	Kirk, S.J. et al., (1995)	Johnston	Mithraratne	…	Page	Oswald	Life-spans in this study *
			(New Zealand)	(New Zealand)	Effective 1 April 1993			(New Zealand)	High, average, low (New Zealand)	(Switzer land)	(NZ)		**Low/average/ high**
					(New Zealand)								
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
	Plasterboard lining							40		40		50	30, **40**; 50

	Material	Adalberth	Jaques as quoted by Mithraratne	Jaques,	Rawlinsons	Fay, as quoted by Mithraratne (Australia)	Kirk, S.J. et al., (1995)	Johnston	Mithraratne	…	Page	Oswald	Life-spans in this study *
			(New Zealand)	(New Zealand)	Effective 1 April 1993			(New Zealand)	High, average, low (New Zealand)	(Switzer land)	(NZ)		**Low/average/ high**
					(New Zealand)								
Roof and floor	Timber frame	50				> 100			50; > 100; > 100	80			**Building life**
	Plasterboard ceiling lining				20	> 100			20; > 100; > 100	30		35	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)

	Material	Adalberth	Jaques as quoted by Mithraratne	Jaques,	Rawlinsons	Fay, as quoted by Mithraratne (Australia)	Kirk, S.J. et al., (1995)	Johnston	Mithraratne	…	Page	Oswald	Life-spans in this study *
			(New Zealand)	(New Zealand)	Effective 1 April 1993			(New Zealand)	High, average, low (New Zealand)	(Switzer land)	(NZ)		**Low/average/ high**
					(New Zealand)								
	Epoxy resin			7									**7**
	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

	Material	**Adalberth**	**Jaques as quoted by Mithraratne**	**Jaques,**	**Rawlinsons**	**Fay, as quoted by Mithraratne (Australia)**	**Kirk, S.J. et al., (1995)**	**Johnston**	**Mithraratne**	**…**	**Page**	**Oswald**	**Life-spans in this study ***
			(New Zealand)	(New Zealand)	Effective 1 April 1993			(New Zealand)	High, average, low (New Zealand)	(Switzer land)	(NZ)		**Low/average/ high**
					(New Zealand)								
	Internal doors, frames	30				60			30; 60; 65	35			30; **40**; 60

Table 31: Estimated useful lifetimes of materials

* assumed lifetime in **bold**