The Exemplar House - a generic LCA model for houses in New Zealand

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ABSTRACT

An improvement of the sustainability of residential buildings is a key issue in New Zealand. Life cycle assessment (LCA) is a useful tool in the environmental assessment of buildings. It can be used to evaluate different alternatives and optimise the design from a life cycle perspective. An LCA model for a typical New Zealand home the "exemplar house" has therefore been developed in order to demonstrate the use of LCA in decision making processes.

The model compares six different building designs, three climatic regions, three fuel types for heating and two different heating schedules, which are all day heating and intermittent heating. The study has shown that the non renewable consumption for the operational energy accounts for between 30 and 80 % of the overall life cycle energy. The life cycle impacts of a concrete floor with regard to thermal mass are also taken into account. This demonstrates the importance of using the right building materials in the right context. The tool will be used as a generic research tool which provides a link between building material development and the improvement of the New Zealand building stock.

Key words

Life cycle assessment, LCA, house, environmental impact, maintenance, operational energy

1 INTRODUCTION

A key factor in achieving more sustainable housing next to social, cultural and economic aspects is the environmental aspect. Environmental issues include energy use (by people living in a house, but also in producing building materials), the emissions related to energy use, resource consumption, and waste generation. The following examples best illustrate these issues:

- Domestic energy consumption is about 13 % of the total energy consumption in New Zealand (Ministry of Economic Development, 2006).
- Nearly a third of all electricity is used domestically – in heating, lighting, and running appliances (Ministry of Economic Development, 2006).

- Waste from construction and demolition may represent up to 50 % of all waste for disposal (Ministry for the Environment, 2006).

An overall approach and input by all stakeholders, throughout the life cycle, is required to address the environmental issues. A number of steps need to be taken; firstly the key issues need to be identified, alternatives have to be assessed and existing technologies and products need improvement. Environmental life cycle assessment provides a suitable tool for assessing the environmental performance of a building; by taking a systems perspective over the whole life cycle of a product or service.

In this study, the environmental impacts of an average New Zealand house were analysed with the help of LCA. The exemplar house, designed by Willson (2002) is a basic two storey house with three bedrooms and a garage and a total floor area of 195 m^2. Exemplar House was chosen for this study, since it has already been used in other studies in New Zealand. Detailed drawings and a quantity survey were available for this house. The exemplar house is regarded as a typical house for New Zealand.

2 METHODOLOGY

Life cycle assessment is an analytical tool for the systematic evaluation of the environmental impacts of a product or service system throughout all stages of its life. LCA extends from the extraction and processing of raw materials through to manufacture, delivery, use and finally on to waste management. Because the LCA methodology is relatively complex, ISO standards (ISO 14040 and 14044) have been developed to improve consistency in the methodology. This framework is used for the study of the exemplar house.

ISO standard 14040 defines four generic steps in the LCA process:

- Goal and Scope Definition: The goal and scope of an LCA study are to be clearly defined in relation to the intended application of the study
- 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
- Impact Assessment (Results): The impact assessment translates the results of the inventory analysis into environmental impacts (e.g. climate change, ozone depletion). The aim of this phase is to evaluate the significance of potential environmental impacts
- Interpretation (Conclusion): In this phase conclusions and recommendations for decision-makers are drawn from the inventory analysis and the impact assessment

The structure of this paper follows this framework.

2.1 Goal and scope definition

The goal of the study was:

- to compare the environmental impacts of six design alternatives of the exemplar house
- to find the environmental hot-spots
- to analyse the ratio of the embodied and operational environmental impacts
- to develop an LCA model for further research projects
- to develop a generic LCA model for houses for communication with stakeholders.

The key concept in LCA is the systems approach. This means on the one hand to look at the whole life cycle of a building material from cradle to grave and on the other hand to focus on the function rather than the material. Rather than looking at a certain mass of material it looks at the function or the service which is provided by a certain product. In a building context that means that the emphasis shifts from the product level to building component level. For example the comparison between 1 tonne of construction steel, 1 tonne of timber, and 1 tonne of concrete would not comply with this approach. The functional unit, i.e. the basis for a comparison would be “one square metre of an external wall for a one storey residential building for a 50 year period”. The respective masses of steel, timber, and concrete would be calculated on this basis.. The definition of a functional unit is therefore a crucial element in any LCA. The functional unit provides a basis for the quantification of the system under analysis.

The functional unit for this study was the exemplar house over a 50-year period in New Zealand in different locations and with different heating technologies. For the base scenario, the house was located in Wellington and heated with an electric heater in the evening only at a level of 18 °C. The effect of different climates (Auckland, Queenstown), different heating schedules (all day) and fuel types (natural gas and wood) were also analysed. The material options included a suspended timber floor or a concrete slab on ground, timber weatherboard, fibre cement or brick veneer cladding and a steel or concrete tile roof (Table 1).

Table 1: The material six design alternatives considered in this study

Name	Floor	Wall cladding	Roof cladding
Timber/WB/steel	Suspended timber	Weatherboard (WB)	Steel
Timber/FC/steel	Suspended timber	Fibrecement (FC)	Steel
Concrete/WB/steel	Slab on ground concrete	Weatherboard	Steel
Concrete/FC/steel	Slab on ground concrete	Fibrecement	Steel
Concrete/brick/steel	Slab on ground concrete	Brick veneer	Steel
Concrete/brick/concrete	Slab on ground concrete	Brick veneer	Concrete

The scope of the study included construction, maintenance, operation and end-of-life. Construction included the manufacturing and transport of the raw materials and products. Transport from producer to the building site and from the building to the landfill was also considered.

The environmental impacts were assessed according to an internationally accepted methodology (CML 2000 baseline method). The chosen impact categories were global warming, ozone depletion, eutrophication, acidification, photo-oxidant formation and non-renewable primary energy demand.

2.2 Inventory analysis

The inventory analysis presents the results of detailed material and energy balances over the system identified in the Goal and Scope Definition. All quantities of material and energy inputs, product and emission outputs to air, water, and land are compiled into one inventory. The overall product system should extend upstream to the extraction of primary resources, and downstream to the point where material is disposed of. Treatment of solid waste should therefore be considered as part of the product system.

In the inventory analysis of the exemplar house 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. The data quality for the inventory analysis is good. Since full LCA datasets for New Zealand specific building materials are currently not available (energy use and CO_2-emissions only), overseas data were used. The main data source was the database of the LCA software GaBi (IKP, PE 2002).

There was no data for carpet in the GaBi database. A dataset was created based on the material quantities given in Potting (1994) for polyamid based carpets. This dataset has been verified with other literature data. For the carpet production, the energy demand and material use given in Potting was taken into account.

For wood treatment, there were no data available and therefore it was not included at this stage, but will be included in the next steps of the project.

The inventory analysis was divided into built-in materials, maintenance and operational energy. The data sources for these life cycle stages are described below.

Built-in materials

Built-in material quantities were based on Willson (2002), Zyl and Page (2005), and calculations. The house in Queenstown differs slightly from the houses in Auckland and Wellington, due to the requirement of more insulation and double glazing. Quantities include off-cuts from the construction site.

Maintenance

Maintenance activities involve everyday measures, such as repairs or decorating as well as heavy maintenance such as restoration or replacement of building elements and service systems. The estimated lifetime of building materials and their replacement rate (Table 2) was based on literature (Jacques 1996, Fay 1999, Adalberth 1997, Mithraratne 2001, Rawlinsons 2004, Johnstone 2001, Page 1997 and 2002, Steiger 1995 and Oswald 2003).

Table 2: Estimate useful lifetimes

	Material	Life-span considered in this study
Buildings		50
Substructure	Timber piles, concrete slab	Building life
Floor	Floor framing, joists, flooring	Building life
Walls	Wall framing (timber)	Building life
	Insulation, skirting, brickwork, mortar, cavity ties, flashing	
	Fibre cement	50
	Weatherboard, wooden panelling	40
	Brick	80
	Plasterboard lining	40
Roof and floor	Timber /steel roof frame	Building life
	Plasterboard ceiling lining and battens	40
	Steel roofing sheets, battens, insulation	40
	Concrete tiles and battens	60
	Gutters and down pipes (PVC)	25
Finishes	Wallpaper	10
	Carpet	10 (plastic)
	Vinyl	15
	Interior paint doors, trim, ceiling	8
	External paint cladding, doors	8
	External paint roofing	10
Joinery	Window frames, glazing	40
	External doors, frames	40
	Internal doors	40

It was assumed that the load-bearing structure (wall, floor and roof framing) was not changed or replaced during the building life. Small repairs were neglected.

Another issue is how to calculate the number of replacements in the life cycle assessment. The components can be taken into account in a pro rata basis or as their actual replacement. With the pro rata approach a component with a life of 20 years in a building with a service life of 50 years, would be replaced 50/20 -1 = 1.5 times. If the actual replacement is accounted for, the actual replacement time of 2 is considered (Kotaji et al 2003). Both approaches have pros and cons. On the one hand, no prorating considers the actual activities. On the other hand, prorating reflects the average situations and the uncertainties in life-spans and replacement cycles better. If no prorating is applied, replacements occurring close to the end of the building life are very uncertain. The choice of the approach might cause significant differences in the LCA results. In this study, prorating was applied due to the high level of uncertainties.

Operational energy

Related to the use of buildings is the use of energy for heating, hot water preparation, lighting, and possibly for cooling and ventilation. Energy efficiency is of great importance for all types of energy usage. However, the aim of this study was to analyse and find opportunities for optimisation of the building design and the choice of building elements. Therefore only the components directly related to the building were considered. Hot water energy demand, for example, is not determined by the building itself, but by the number of occupants, their habits and the type and efficiency of the water heating system. Lighting and mechanical ventilation are related to the building to some extent, but the size and location of the openings, influence the level of daylighting and natural ventilation as well. The most significant building-related components are heating and cooling. They are mostly determined by the building envelope, the solar gains and the thermal mass, while they are also to a great extent influenced by the user behaviour.

In this study only the heating energy demand of the house was considered. While cooling has become more widespread in the northern parts of New Zealand, it is still not a common option for residential buildings. Hot water preparation, lighting and ventilation were not taken into account, since these are not, or only to a small extent, related to the building.

The heating energy demand of the house was calculated with the software tool ALF3 (Annual Loss Factor), developed by BRANZ (Stoecklein and Basset 2000). ALF3 estimates the annual heating energy demand of the house design by taking into account, the orientation of the house, thermal mass, air leakage rate and heating habits of the occupants.

3 RESULTS (IMPACT ASSESSMENT)

Several environmental impact categories were considered in the impact assessment. Besides the primary energy use, global warming, acidification, euthrophication, ozone depletion, photo-oxidant formation potentials were calculated.

The results were calculated for each step of the life cycle, i.e. construction, maintenance, usephase and disposal, in order to identify where the hot spots are.

In the base scenario (Wellington, evening heating, 18 °C, electric heater), construction and maintenance together were responsible for around 40 % of the impacts over 50 years. In the categories ozone depletion and photo-oxidant formation, this ratio was even higher: 85 % and 70 %, respectively (Figure 1).

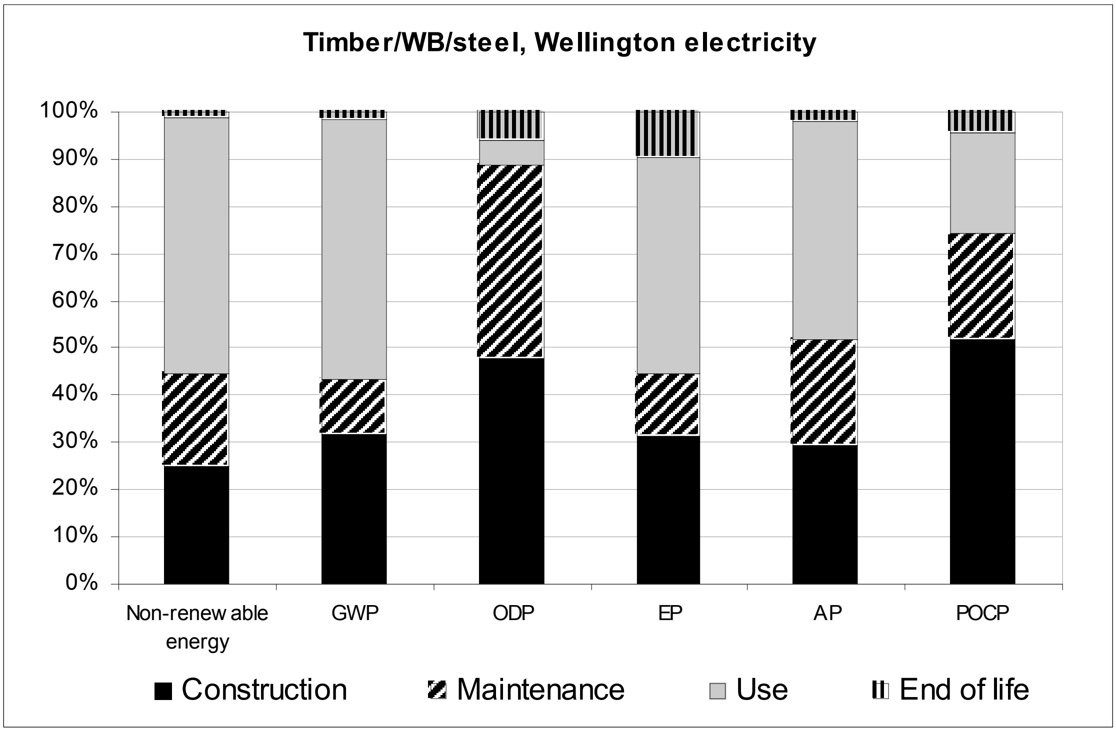

Figure 1: Life cycle impacts of the exemplar house

For the whole life cycle, the concrete/ fibrecement/ steel option had the highest results in most impact categories and the timber/ weatherboard/ steel construction the lowest. This can be explained with the low values of the timber/ weatherboard/ steel house in the construction and operation phase and the lower heating energy demand (Figure 2).

In weight, the most dominant building materials were concrete, gravel and sand in the hardfill, timber and gypsum board. The total weight of the houses with concrete floor was about double that of the houses with timber floor. However, concrete, gravel and sand had relatively low environmental impacts. The hot-spots in the construction were metals (aluminium and steel), fibre cement and carpet. The contributions of these materials were high in every impact category compared to their weight. In the maintenance phase, the replacement of carpet and repainting caused significant impacts.

Impacts caused by maintenance were slightly higher than for the other houses due to the higher maintenance requirement of the cladding. The great amount of wood applied in this house resulted in a large carbon sink and low global warming potential. The amount of stored carbon exceeded the greenhouse gas emissions from the building material production.

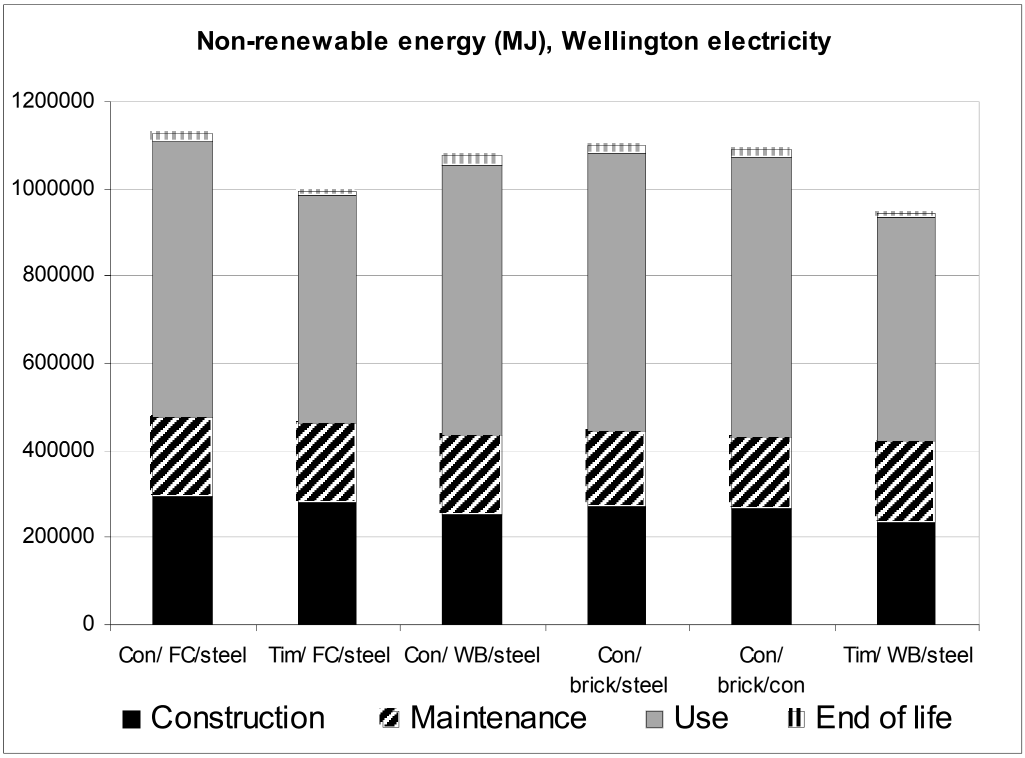

Figure 2: Non-renewable energy demand for the whole life cycle of different house designs

The life cycle impacts of a concrete floor with regard to thermal mass were also taken into account (Figure 3). This demonstrates the importance of the use of the right building materials in the right context. Thermal mass of a concrete floor has only shown a positive effect in a 24 hour heating scenario. The disadvantage of thermal mass in a colder climate (Queenstown) in an intermittent heating scenario is due to the requirement to heat up the thermal mass. However, it has to be stated that the concrete floor in this study has not been fully insulated, but fulfilled the requirements of the building code. The results would be different for an insulated concrete floor.

However, the choice of fuel also influenced the results. Wood burning was the most favourable in non-renewable energy demand and global warming, but had very high impacts in the other categories. Electricity had lower values in non-renewable energy demand than gas due to the high share of hydro power in the New Zealand electricity mix. However, in the other categories the electricity values were higher.

The scenario analyses proved that user behaviour and fuel type strongly influence the results. In some cases, differences between locations were smaller than differences due to heating schedules. This means that the impacts caused by a house in Queenstown, which is heated in the evening only to 18 °C were sometimes lower than the impacts of a house in Auckland with whole day 20 °C heating. The ratio of the embodied and operational impacts was also different. At present, evening heating only at relatively low temperatures is typical for New Zealand. In this case, the type of materials had significant influence on the results. If higher temperatures are maintained during the whole day, the use phase becomes more dominant. With increasing thermal requirements of users this scenario may become more common in the future. In general, houses with timber floors had lower heating energy demand if only evening heating was applied and those with concrete floors if the house was heated the whole day.

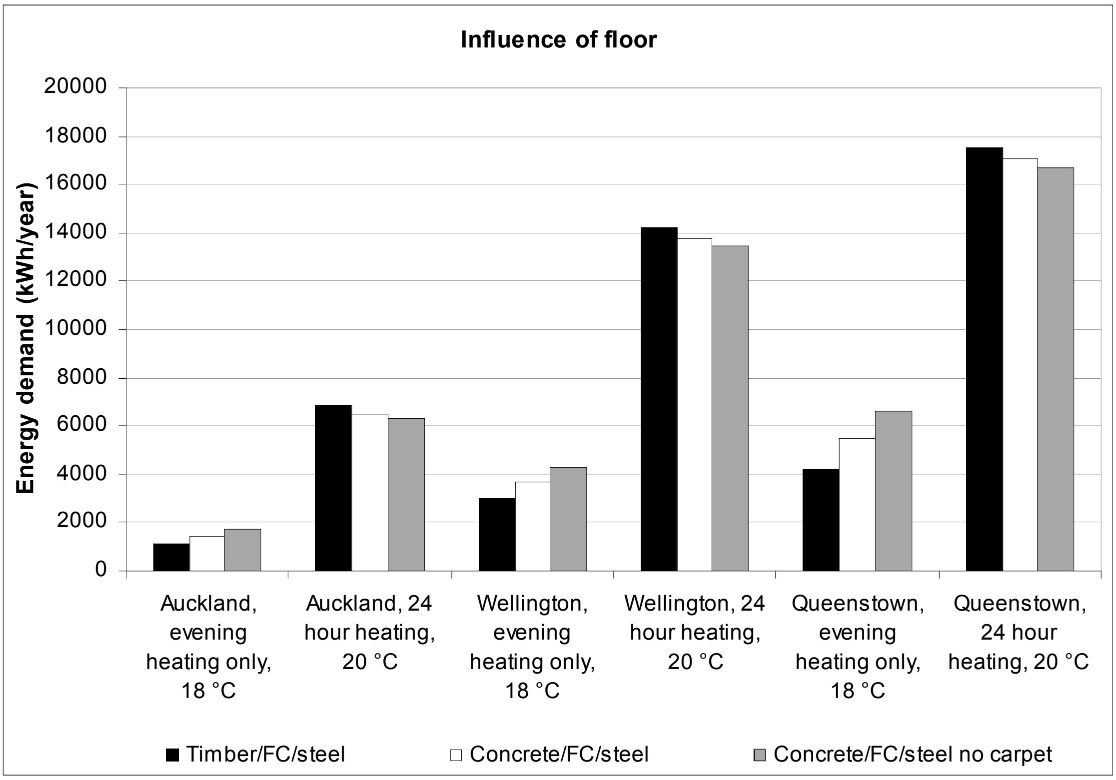

Figure 3: The influence of thermal mass on the life cycle energy demand

4 CONCLUSIONS (INTERPRETATION)

The study has demonstrated the LCA is a useful tool for the holistic analysis of a building from an environmental point of view. It can be used to evaluate different alternatives and optimise the design from a life cycle perspective. Taking the operational energy demand as well as the embodied energy of the materials into account provides an insight into the relation ship between materials and heating requirements.

The operational energy demand, as well as the contribution of the impact categories is higher than published figures for situations in Europe. The embodied impacts therefore play a very important role in the New Zealand context.

Heating for 24 hours a day is very uncommon in New Zealand. In a colder climate and without the addition insulation of the concrete slab, the benefits of additional thermal mass can therefore not always be realised. Timber as a building material can lead to lower environmental impacts in a New Zealand house, where the potential of thermal mass might not be fully utilised.

The study has been used to demonstrate the use of LCA for the assessment of building materials and house designs to stakeholders of the building industry in New Zealand and will be used as a generic research tool which links between building material development and the improvement of the New Zealand building stock. Further scenarios will include the modelling of a building with higher insulations standards.

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