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A Comparative Life Cycle Assessment of Alternative Constructions of a Typical Australian House Design

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www.fwpa.com.au
FWPA Level 4, 10-16 Queen Street,
Melbourne VIC 3000, Australia
T +61 (0)3 9927 3200 F +61 (0)3 9927 3288
E info@fwpa.com.au W www.fwpa.com.au

A Comparative Life Cycle Assessment of Alternative Constructions of a Typical Australian House Design

Prepared for

Forest & Wood Products Australia

by

Andrew Carre

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Principal Researcher:

Andrew Carre
The Centre for Design
RMIT University

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Forest & Wood Products Australia Limited
Level 4, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

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2 Introduction

Among OECD countries, the residential and commercial building sectors are understood to account for about one third of primary energy use. This is in addition to the energy used for producing the building materials, components, assemblies and the transport of building materials. The building and construction (non-building) sectors also account for 30-50% of all commodities consumed (by weight) and generate 40% of solid waste (OECD 2002; OECD 2003). As environmental pressures such as climate change and resource scarcity become more acute, the capacity of finite material resources to sustain human consumption is brought into question (Global Footprint Network 2007). Reducing the footprint of the built environment requires solutions that improve building efficiency, both in an operational sense and a material sense. In seeking to achieve these improvements, techniques such as Life Cycle Assessment (LCA) provide useful insights into the sources of burdens that can help to identify design options that reduce these impacts (ISO14044(2006)).

In an Australian context, sustainability is increasingly becoming a key consideration of building practitioners, policy makers and industry alike. As solutions are sought to reduce the impacts of buildings, LCA is seen as an objective measure for comparing building designs that avoids problems, such as ‘burden shifting’, apparent in more subjective approaches that focus on single environmental issues in isolation (UNEP 2004). In order to support and further the use of LCA in building related decision making, initiatives such as the AusLCI project have been established to develop and retain the data needed to undertake LCA.

In addition to the general interest in LCA, building regulators have demonstrated a commitment to improving the energy efficiency of new residential buildings through initiatives such as 5 star minimum performance requirements. By making energy efficiency a mandatory requirement, regulators have raised the profile of the operational phase of building life, changing detailed aspects of the way residential buildings are designed and constructed.

Drawing from these themes, this study explores the application of LCA through the assessment of a typical Australian home. The study seeks to apply LCA to determine the impacts of a typical house design, while at the same time testing newly available inventory data for timber products. In doing so, the study also explores the implications of uniform building efficiency requirements as viewed through an ‘LCA’ lens. While the study does seek to contrast alternative material combinations within a single design, its core objective is an exploratory one that seeks to identify underlying issues for building practitioners in an environment where methodologies such as LCA and mandatory building performance are forming key elements of building design criteria.

3 Goal of the study

The primary goal of the study is to compare the potential environmental impact of a typical Australian house design when it is constructed from alternative, commonly used, material combinations. In drawing the comparison, a range of construction locations are considered.

The house design assessed is the Housing Industry Association's (HIA) single storey standard house design which has been developed by the HIA to reflect a commonly constructed design in cost benchmarking studies. The standard house is a three bedroom, 2 bathroom home with a floor area of approximately 200 m2, including garage. Construction material combinations assessed in the study are as shown in Table 1.

Table 1 Construction types to be compared.

Construction type	Cladding	Frame	Roof	Floor	Heating and cooling performance
a	Brick	Timber	House - concrete tile Garage - steeldeck	Elevated	5-star
b	Brick	Timber	House - concrete tile Garage - steeldeck	Slab	5-star
c	Brick	Steel	House - concrete tile Garage - steeldeck	Elevated	5-star
d	Brick	Steel	House - concrete tile Garage - steeldeck	Slab	5-star
e	Timber weatherboard	Timber	House - concrete tile Garage - steeldeck	Elevated	5-star

In this study, insulation and other techniques are used to ensure each house compared achieves a 5-star energy performance rating as measured under the Nationwide House Energy Rating Scheme (NatHERS). Adjustments necessary to achieve 5-star heating and cooling performance are achieved using methods that minimise associated incremental embodied energy.

Comparisons are undertaken at three locations, reflecting a wide range of climatic conditions relevant to new house construction undertaken in Australia. Climate zones considered are as shown in Table 2.

Table 2 Climate zones considered in energy modelling.

Location	NatHERS Climate zone	Building Code Climate Zone	Description
Melbourne	21	6	Mild, temperate
Sydney (Eastern)	17	5	Warm, temperate
Brisbane	10	2	Warm humid summer, mild winter

Secondary goals of the study include testing the newly developed timber products Life Cycle Inventory (LCI) in a real world application, as well as educating and informing the intended audience as to the role LCA might play in assessing the potential environmental impacts of residential buildings going forward. Where possible, concepts emerging from work being undertaken by the AusLCI project and supporting Building Products Innovation Council (BPIC) project to develop LCA protocols and inventory data (Howard and Sharp 2008), are addressed and incorporated.

3.1 Intended audience

The audience for this study is intended to be the timber products industry as represented by Forest and Wood Products Australia (FWPA), other building materials groups involved in the AusLCI project, building and design professionals and building/construction regulators. The study is intended to be a guiding document that informs readers as to the impacts and issues associated with the construction types concerned, as well as the LCA assessment methodology. The study may also be used to make relevant claims regarding the performance of timber products to a broader public audience.

3.2 Review committee

ISO14044 (2006) requires that LCA studies making comparative assertions to be disclosed to the general public be peer reviewed by a panel of interested parties. In accordance with this requirement the study has been peer reviewed by a panel of experts, representative of the building products and construction industries. It has also been reviewed by an independent, expert LCA reviewer (Harry Van Ewijk, IVAM). Although declining to participate in report development, government policy makers have indicated a desire to review the report findings once it is released.

3.3 Acknowledgements

The author would like to thank the members of the industry review committee who volunteered their time to review the work who provided invaluable feedback; Chris Lafferty at FWPA for assistance throughout the project; and, Alastair Woodard at TPC Solutions for his dedicated review of many report drafts and his many insightful suggestions and comments.

4 Literature review

Before considering conclusions drawn from the literature it is worthwhile considering the diversity of approaches taken, which are well represented by the studies shown in Table 3. Although most LCA's are done in accordance with the ISO14040 series of standards, ISO does not prescribe how comparisons should be undertaken nor what should, and should not be included, but it does govern key elements that should be addressed in the studies, allowing some broad comparisons to be drawn.

A requirement of the LCA standard is the definition of a functional unit of comparison. The functional unit defines how results will be reported and is intended to allow comparisons to be drawn between products that provide similar functions yet exist in different forms. In the studies considered this unit of comparison was defined as either 'per square meter' or 'per house'. The 'per house' units were useful only for comparing houses of similar floor space, yet the 'per square meter' comparisons opened up a wider range of potential comparison. In essence, the distinction between units is academic as readers could readily perform conversions from house level units to square meter units should they so choose. Given the similarity in floor space between the houses studied, issues associated with nonlinearities when scaling would be expected to be minimal.

The types of buildings considered in the literature varied widely and only those of particular relevance to this study are presented in Table 3. Within this group, key differences in architecture are observed between geographic locations that need to be considered when comparing study outcomes. For example North American homes assessed in Lippke, Wilson et al. (2004) can contain basement foundations, whereas most other studies tend to use a concrete slab foundation. Other key differences are that some studies consider double storey buildings and some single storey buildings. Of the studies considered, the Maddox and Nunn (2003) study most closely reflects the archetypes considered in this study.

Geographic aspects of studies are also likely to impact results, especially global warming impacts associated with the operation of buildings during their use phase of life. Studies based on European experience may have lower emissions per unit of energy consumed during use versus North American and Australian Studies. Other geographic differences are also likely to exist such as differences in climate.

When determining life cycle impacts, system boundaries typically represent a source of significant diversity between LCAs concerned with a similar topic, however the boundaries used in the studies considered appeared to be remarkably consistent. Life cycle phases associated with material manufacture through to construction, use or operation, and end of life have all been considered. As have detailed aspects such as transportation of materials. Areas of variation occur at a detailed level, with most studies excluding or not addressing the construction process itself, as well as differences in building operation and maintenance.

Operational assumptions are typically varied according to the building design, which can have a significant impact on results. For instance, global warming potential is predominantly driven by the operational phase of life in the studies considered (up to 90% of total impact (Maddox and Nunn 2003)), so studies that allow operational impacts to vary between designs tend to conclude based on operational performance, rather than other aspects of the building lifecycle. The CORRIM study (Lippke, Wilson et al. 2004) takes an alternate approach that adjusts the building designs to achieve constant energy performance, making the comparison more about the inherent properties of the materials. This approach is similar to that selected for this study. Neither approach is considered superior as both approaches serve to address different goals.

Additional operational components beyond heating and cooling, such as lighting, cooking, waste disposal and other aspects were also considered by some studies. In such cases the assumptions were usually consistent across house designs so did not serve as points of differentiation.

Building-life assumptions are critical to determining the total impact of a building over its life as well as the ratio of building impacts between those associated with operation and the other lifecycle stages. Amongst the studies considered, a range of building lives were considered ranging from 50 to 80 years. Justification for such assumptions were typically limited with most studies acknowledging the arbitrary nature of the building life assumption.

Table 3 A comparison of different LCA studies on residential buildings.

Study	**'Life cycle assessment applied to the comparative evaluation of single family houses in the French context' (Peuportier 2001)**	**'CORRIM: Life-Cycle Environmental Performance of Renewable Building Materials' (Lippke, Wilson et al. 2004)**	**'Sustainability based on LCM of residential dwellings: A case study in Catalonia, Spain' (Ortiz, Bonnet et al. 2009)**	**'LCA Fact Sheet: Life cycle analysis of clay brick housing – based on a typical project home' (Maddox and Nunn 2003)**
Functional unit	1 m^2 living area	Total house	1m2 usable floor area	Total house
House size	112-212m2	190-200m2	160m2	127m2
Buildings considered	All single storey: 1) Concrete slab, concrete block wall, clay tile roof (112m2) 2) Concrete slab, timber frame wall (cladding unclear), vegetal roof (212m2) 2) Concrete slab, timber frame wall (cladding unclear), clay tile roof (unknown area)	1) Minneapolis house, double storey typical of design in area (190m2): a) Concrete block basement, timber sheathing and vinyl siding walls, timber frame asphalt tile roof b) as above but using steel frame 2) Atlanta house, single storey design typical of houses in area (200m2) a) Concrete slab floor, timber sheathing and vinyl siding walls, timber frame asphalt tile roof b) as above but using concrete block veneer walls	LCA of a typical Spanish Mediterranean double storey house located in Barcelona (160m2). Concrete slab floor (lower), timber floor (upper), brick walls, clay tile roof	1) Brick veneer/timber frame/concrete slab 2) Brick veneer/steel frame/concrete slab 3) Double brick/concrete slab. 4) Timber clad/steel frame/concrete slab. 5) Timber clad/timber frame/concrete slab
Building life	80 years	75 years	50 years	60 years
System boundary	Includes materials and energy used, emissions. Takes into account direct fluxes caused by external processes such as transport and electricity generation.	Considers source extraction through to the completion of the shell onsite, its use, maintenance, and disposal.	Includes pre-construction phase, operation phase (use and maintenance) and dismantling phase	Includes production of building materials and construction of the house, utilisation over a 60-year period, and decommissioning at the end of the life cycle.
Maintenance	Replacement of various components.	Included.	Replacement of all flooring, Quarry tiles, replacement of all windows and external doors	Included.
Operation details	Heating, hot water, appliances, lighting, daily waste disposal. HVAC varied between designs.	Heat and cool only. Energy use kept constant for each house type.	Heating, hot water, cooking, appliances, lighting	Lighting, appliances, hot water and HVAC included. HVAC delivered by reverse cycle and varies between designs.
Country	France	USA	Spain	Australia
Time frame	2001	2004	2008	2003

The results of the studies considered varied depending on the environmental indicators considered. The most common indicator selected was global warming potential, followed by embodied energy (or cumulative energy demand).

It is difficult to summarise the wide range of outcomes derived from the studies shown in Table 3 as there is range of functional units applied, as well as a range of environmental indicators assessed. In an attempt to compare the study outcomes and set a context for this study, the global warming indicator was assessed for each study using a common functional unit, defined as one square metre-year (m2.a) of building service. Individual study outcomes were then manipulated based on published building lives and areas to achieve results in terms of this functional unit.

Interpolation was also required in two instances. The first being the calculation of global warming potentials for the life cycle for the Lippke study, by using embodied energy ratios as a guide to scale published construction global warming impacts. The second involved the exclusion of 'other utilisation' impacts in the operational phase, beyond heating and cooling (such as appliance use), in the Maddox study, which skewed results (Lippke does not include these).

Figure 1 and Figure 2 illustrate the range of outcomes from the studies considered for the global warming indicator when restated in terms of the function unit "square meter-year".

The charts illustrate the themes that emerge from studies as well as some of the contradictions.

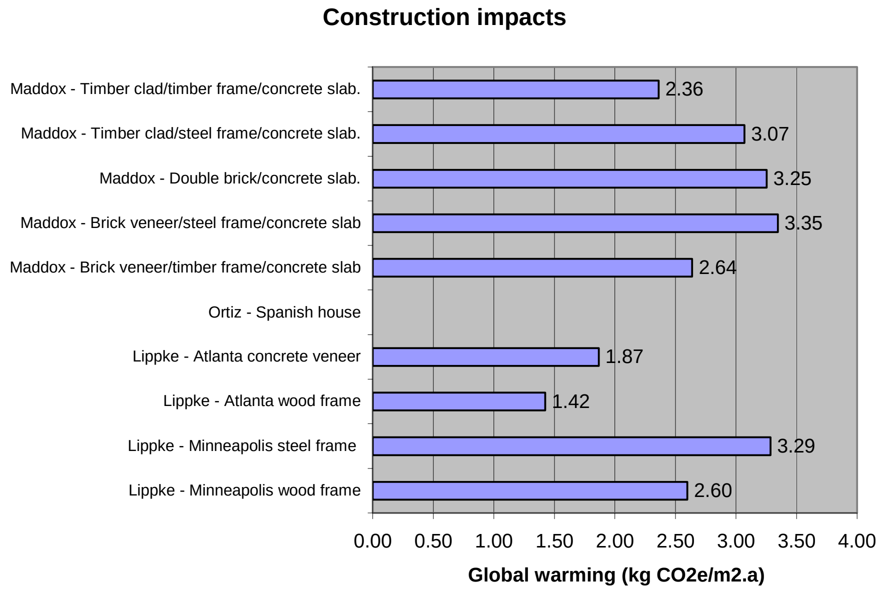


Figure 1 Construction impacts for comparative studies (global warming). Ortiz not published.

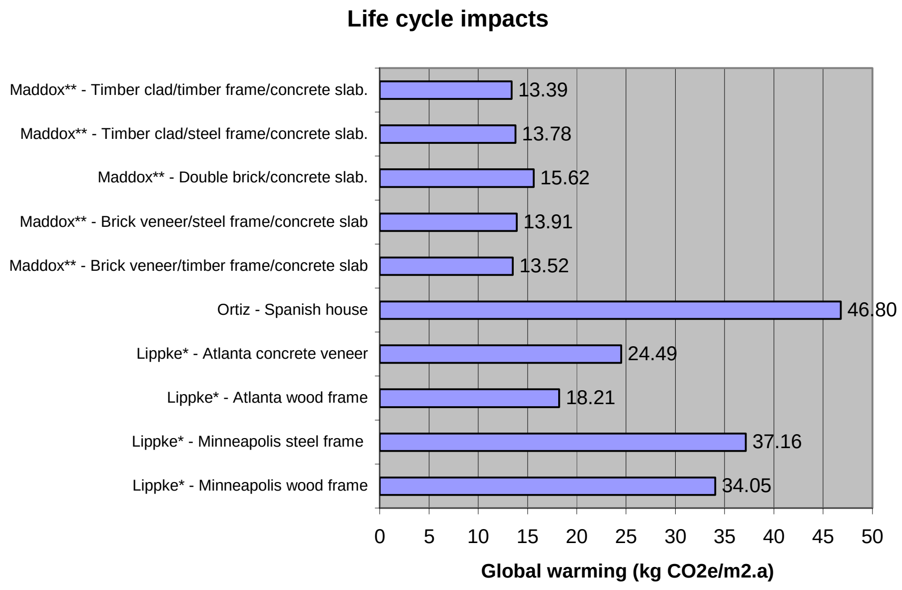


Figure 2 Life cycle impacts for comparative studies (global warming).

The studies are directionally consistent when it comes to the ratio of operational impacts versus other impacts, with operation contribution 76-92% of total life cycle impacts for global warming. The Lippke study tended to have a higher operational component than Maddox which could be due to higher heating and cooling loads in the climates considered.

Differences in life cycle impacts associated with substituting steel for timber in the structures also appeared directionally consistent. Lippke reports an increase in life cycle impacts for the Minneapolis house of 9%, whereas Maddox reports an increase of 3% when steel is introduced in place of timber in wall and roof structures.

Overall, global warming impacts over the life cycle of the buildings considered varied from 13.39-46.80 kgCO2e/m2.a. The Maddox study tended to have the lower impacts (after the adjustment mentioned earlier) and Ortiz and Lippke had the higher impacts. The range is understandable when operational energy is considered as the Lippke buildings had far higher heating and cooling load requirements (4575-7800GJ per house life, versus 723-856GJ per house life for Maddox).

In general, the literature provides a range of results that can be used to compare and contrast the results obtained in this study, particularly against the core indicators of global warming and embodied energy, which have been derived from using broadly similar approaches. Other indicators of environmental impact are not prevalent in the literature making triangulation of study results difficult.

5 Scope of study

5.1 Functional unit

The purpose of the functional unit is to provide an equitable measure to compare the houses considered that is solely based on the service provided by the house. Defining the core function of a house is not straightforward as houses provide a myriad of functions including shelter, storage, status indication, entertainment, visual amenity etc. Of these, human shelter is arguably a priority, but many would argue storage functions (such as the provision of a garage in this case) are not superfluous and need to be considered. The decision as to what to define as core function has been debated within this project and has changed on a number of occasions.

The outcome determined strikes a conservative definition of function as the provision of floor-plan area, part of which is climate controlled. By striking the functional definition broadly, the designs assessed can be considered in such a way that incorporates the functionality of the garage space provided in the building. This functionality is also in keeping with the goal of assessing a 'typical' Australian house design, which often includes this space.

Exclusion of the garage space from the functional unit would have burdened the remaining living area with the impacts of the garage, which was felt to distort rather than enhance the presentation of results.

Also considered in defining the functional unit is the need to undertake analysis and comparison of outcomes at different building lifetimes. To facilitate this, the functional unit is also time bounded to one year of function provision. The resulting functional unit is as follows:

> **Functional unit: 1 square meter of internal floor area (including double garage), 76%[1] of which is climate controlled, for 1 year.**
>
> **Units of function are square metre years (m^2.a). Results are presented in terms of impacts per m^2.a.**

Results are shown in terms of this unit, unless otherwise stated.

5.2 System boundary

In determining the life cycle impacts of the construction types described in Section 3, the unit processes shown within the system boundary have been considered as shown in Figure 3.

Unit processes have been included within the boundary that relate to the construction types assessed, rather than household impact. Materials and construction processes are included as well as end-of-life waste treatment processes. As construction types potentially affect thermal performance of the building, heating and cooling operational impacts have been included, as have maintenance impacts. Excluded from the study are other operational impacts such as appliances, household domestic waste generation, water consumption etc. as there is limited connection between these processes and the building construction type.

[1] All rooms climate controlled, with the exception of the garage and the laundry.

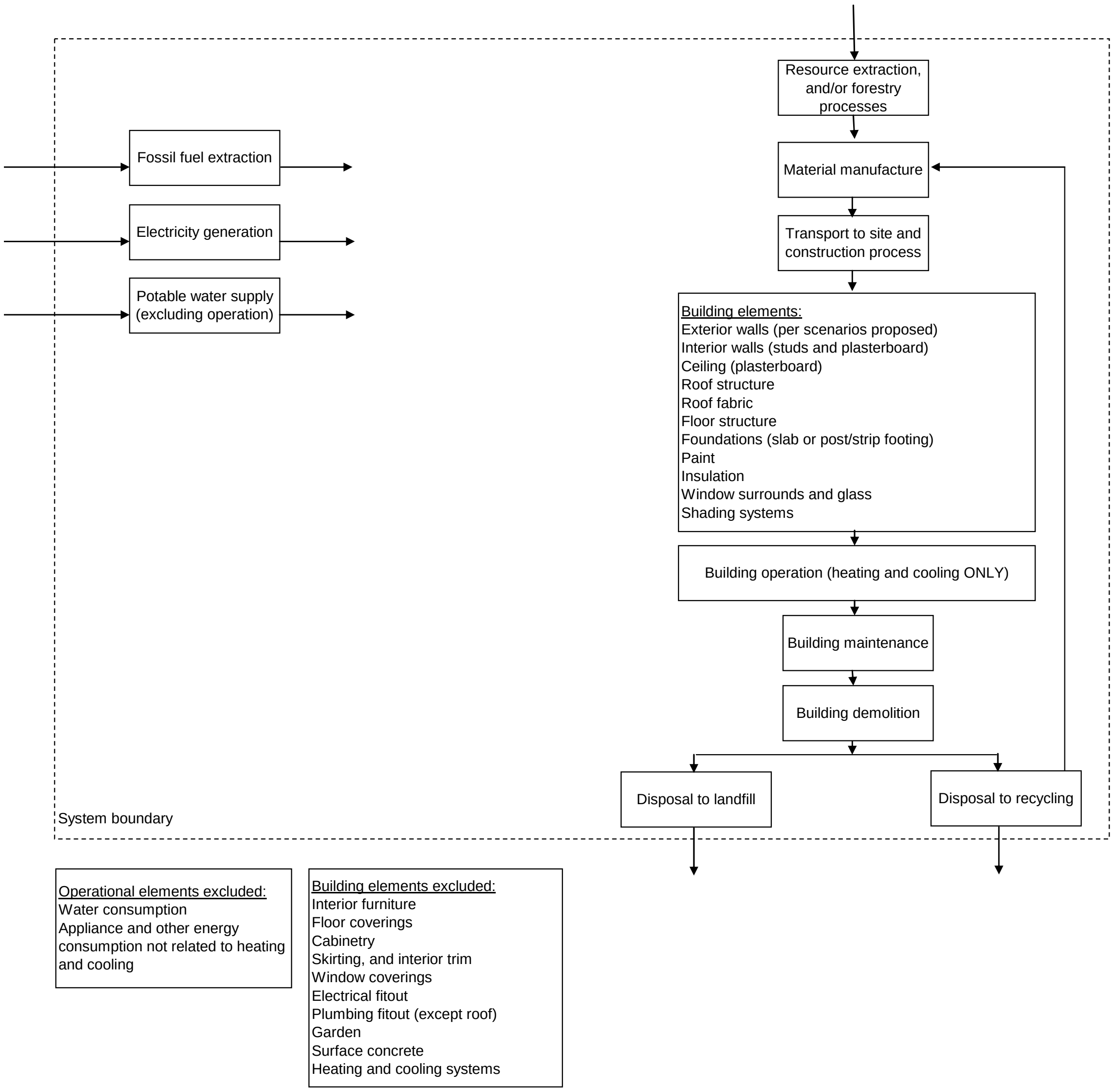


Figure 3 System boundary diagram.

Notable exclusions from the system are interior decoration, furnishing, floor coverings, cabinetry, skirting and trim, window coverings, electrical fit-out, plumbing fit-out, garden, surface concrete, mechanical systems infrastructure (operational heating and cooling to be included, but not the device itself).

5.2.1 Products derived from agricultural or forestry processes

Certain materials, including timber, are extracted from agricultural or forestry processes. In such cases the impacts of the agricultural/forestry processes are taken into account. This includes the propagation and farming of trees or other crops necessary to feed the industrial processes that produce the materials.

Such cycles also involve the absorption and emission of carbon. In this study, biogenic carbon flows are not tracked explicitly as they do not contribute to anthropogenic global warming (IPCC 2006). Carbon ‘credits’ are only assessed when biogenic carbon flows are considered to be stored or sequestered.

With the exception of one sensitivity study, undertaken in Section 10.3, carbon storage is not assessed for the timber products during the use phase of building life. Carbon storage is only considered for timber products disposed of to landfill and is discussed in Section 7.7.1. A further sensitivity study is undertaken to remove this sequestration assumption in section 10.3.

5.2.2 Building operation and maintenance

Building operation and maintenance are included in the study. Operational impacts are limited to the provision of heating and cooling only. Other operational impacts such as hot water, appliances, lighting etc are excluded from the system considered.

5.3 Limitations

The study has been conceived from inception as a 'desktop' study, and is therefore intended to use only published data to undertake the assessment. The study, therefore, does not specifically address an actual building that has been built. This results in assumptions being required regarding the bill of material quantities and overall operational requirements which are based on theoretical estimates rather than actual measures. While these estimates are believed to be sufficient to compare alternative construction types, they could be further enhanced by a study that involves actual measurements, especially when it comes to construction material quantities and waste on-site.

The base-case study also makes assumptions regarding the storage of carbon in timber within landfills. In this study, a portion of carbon in timber waste is assumed to be stored in landfill for a period of greater than 100 years. The impacts of assumptions relating to the behaviour of timber in landfill are discussed further in Sections 7.7.1 and 10.3.

A further aspect of the study is that the storage of carbon in building structures has not been assessed. A sensitivity study that considers carbon storage is undertaken in Section 10.3.

5.4 Data quality requirements

As part of the inventory section of this report (Section 6), data sources used have been assessed for quality in terms of timeliness, geography, technology, precision, completeness, representativeness, consistency and reproducibility.

In general, data quality needs to be of a high quality for material quantities that make up the houses assessed and operational energy requirements, as these quantities drive study outcomes. Material datasets that make up the bulk of house materials need to of a consistent and high quality as these datasets impact the comparability of the assessments. Datasets considered of lesser importance include end-of-life treatments which tend to represent a smaller component of building lifecycle impacts (although treatment of carbon in landfill can be an important for timber structures). Energy delivery datasets, such as electricity and gas, need to be of a high quality and where possible need to be consistent with material datasets to ensure construction versus operation impact ratios are meaningful.

Table 4 describes a broad assessment of data quality used in this study

Table 4 Data quality assessment.

	Timeframe	Geography	Technology	Completeness	Representativeness	Consistency	Reproducibility
Physical characteristics							
Bill of quantities	< 10 years	Australia	Industrial	>90%	high	high	high
Transport & building assembly	< 10 years	Australia	Industrial	>50%	low	low	low
Household heating and cooling loads	< 10 years	Australia	Industrial	>80%	high	high	high
Material inventories							
Hardwood	< 10 years	Australia	Industrial	>80%	med	high	high
Softwood	< 10 years	Australia	Industrial	>80%	med	high	high
Steel	< 10 years	Australia	Industrial	>80%	med	high	high
Concrete	< 10 years	Australia	Industrial	>80%	med	high	high
Aluminium	< 10 years	Mix	Industrial	>80%	med	low	low
Glass	< 10 years	Mix	Industrial	>50%	med	low	low
Energy and other inventories							
Electricity	< 10 years	Australia	Industrial	>80%	high	high	high
Natural gas	< 10 years	Mix	Industrial	>80%	high	high	high
Transport	< 10 years	Mix	Industrial	>50%	high	high	high
Treatment in landfill	< 10 years	Australia	Industrial	>50%	med	high	low
Recycling practices	< 10 years	Australia	Industrial	>25%	low	low	low

5.5 Allocation procedures

Allocation was avoided through system boundary expansion wherever practical in the study. The default allocation method between co-products was based on mass where no discernable economic difference in the product streams was found.

For recycling and recycled content the ISO14044 standard (International Organisation for Standardisation 2006) suggests the use of closed loop allocation where the recycled material goes back into the original product, or where the recycling is open loop (with recycled material being returned to other products) but where no changes occur in the inherent properties of the material. Treatment of co-products

Allocation for recycled material was assumed to be closed loop, with the recycling of virgin content substituting virgin material after allowance for material degradation. Environmental benefits are equivalent to the impacts of the recycling process, including the material lost in the recycling process, minus the avoided production of either the virgin or recycled material respectively.

Allocation for multi-output processes occurs only in the background LCI databases, of which the most prevalent are timber and diesel production (steel and concrete are produced through single product processes). The timber LCI database used is based on a multi-output process in which the common impacts of timber production are allocated to individual timber products (such as sawn hardwood, particleboard etc.) using an economic allocation technique. The diesel LCI database used is based on a multi-output refinery process in which the impacts of producing refinery products (such as petrol, diesel, fuel-oil etc.) are allocated based on energy content.

5.6 Assessment method

This study utilises a core set of environmental impact indicators to assess environmental impacts. The method adopted is based on the Australian Impact Assessment method which is part of the Australian Life Cycle Inventory Database (ALCI). The method comprises a number of indicators selected for their usefulness in assessing Australian environmental issues. The indicators are calculated using internationally recognised methods as described in Table 5.

The indicators selected are broadly consistent with those recommended by Grant and Peters (2008) in their ‘best practice’ guide to life cycle impact assessment. An exception is the exclusion of the toxicity indicators (Human and Ecotoxicity) which have been excluded due to potential data limitations. Cumulative energy demand (embodied energy) has also been included as it represents a pre-cursor to environmental impacts and a useful reference point for comparing results to other similar studies.

Both global warming and abiotic resource depletion are considered to be appropriate methods as both apply to global environmental issues. Photochemical oxidation is included, but is not regarded as a significant issue in Australia, especially outside of urban areas (Grant and Peters 2008). The indicator is included here as it provides a useful triangulation point that may point to differences between industrial material processes and agricultural processes used in the production of building materials. Eurtophication is also included to assess contrasting agricultural and industrial processes involved, although limitations of the method in an Australian context are acknowledged (Grant and Peters 2008).

Water and land use methods represent the most primitive of the impact assessment methods employed, however the significance of the environmental impacts they seek to approximate warrants their inclusion. Neither indicator recognises the local impacts associated with resource extraction, weighting all elementary flows equally. The result is a broad indication of environmental impact that requires deeper investigation to fully confirm. Careful interpretation of both these indicators is particularly important.

A detailed list of impact assessment factors is shown in Appendix K.

Table 5 Core impact assessment indicators.

Indicators	Unit	Description
Global Warming	kg CO_2eq	Measurement of greenhouse gas emissions into the atmosphere, which cause absorption of infrared radiation that, would have otherwise escaped into space. Increased absorption of infrared radiation leads to an increase in the average temperatures of the Earth. The main greenhouse gases are water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). This indicator is represented as CO_2 equivalent units. Global warming potentials used are based on the IPCC's second assessment report which forms the basis of Kyoto Protocol reporting. These global warming potentials have been chosen to maintain consistency between this report and agreed greenhouse gas inventory reporting under the Protocol.
Photochemical oxidation	kg C_2H_4 eq	Measurement of the increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NO_x), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone. This indicator is of importance in areas where photochemical smog is likely to be a problem, such as in urban transport environments.
Eutrophication	kg PO_4^{3-} eq	The release of nutrients (mainly phosphorous and nitrogen) into land and water systems, which may alter biota, and potentially increase algal growth and related toxic effects. Some concern exists that the current eurtophication model, may not be appropriate for Australian conditions. Of particular concern is possible attention of eutrophication impacts associated with airborne transport of nitrogen substances (Grant and Peters 2008).
Land use	Ha*years or Ha.a	Total exclusive use of land for a given period of time for occupation by the built environment, forestry production and agricultural production processes. Measured in hectares per year. The land use measure used in this study is primitive indicator of environmental impact. It involves a simple addition of all land occupation associated with the unit processes within the system boundary. In doing so the measure gives an indication of environmental impact, but does not address issues such as land conversion or scarcity. For instance, 1 m2 of land occupied in a sensitive rainforest area is allocated the same impact as 1 m2 of land occupied in a rehabilitated industrial area.
Water use	kL H_2O	Net water use including potable, process and cooling water which may impact on water quality, water depletion, and biodiversity. As for the land use indicator, water use is a simple summation of water consumed by the unit processes within the system boundary. It does not address issues such as the capacity of the environment from which the water was extracted to support the extraction. For instance, a litre of water extracted from a sensitive wetlands area is allocated the same impact as a litre of water extracted from a lake in a high rainfall area. Although still a coarse indicator of water related impact, calculation is still worthwhile but must be interpreted carefully.
Solid waste*	kg	The release of solid wastes from production and reprocessing to landfill. Impacts depend on the character of the waste. The solid waste indicator used is arguably not a direct measure of environmental impact, but rather reflects a precursor to impacts that occur once waste is disposed of to land. It is included as it provides useful feedback as to what landfill resources are required to support the unit processes considered, and indicates likely consequential impacts. Other impacts associated with landfill, such as global warming, are addressed within the global warming indicator.
Depletion of mineral resources & fossil fuels	MJ surplus	Measurement of the additional energy required to extract lower quality mineral and fossil resources, due to depletion of higher quality, easily extracted reserves.
Cumulative Energy Demand*	MJ LHV	All energy use including fossil, renewable, electrical and feedstock (energy incorporated into materials such as plastic). The energy indicator has been designed on the basis of the first CML impact assessment method (CML 92 V2.04), but changes have been implemented to get closer to the Australian situation (for instance on the broad range of coal quality that is specific to this region)

*Shaded indicators are not true measures of environmental impact, but rather track issues that are likely to be precursors to environmental impact.

5.6.1 Supplementary impact assessment – BPIC

A secondary objective of this study is to, where possible, incorporate AusLCI related activities where they relate to the topic of study. One such area is in Impact Assessment, where the BPIC project has developed a draft impact assessment method for use in building related LCAs (Bengtsson and Howard 2009).

The method proposed is an endpoint method that incorporates the normalisation and weighting of 13 midpoint categories to determine 4 damage categories and a single score outcome (Figure 4). The method proposed is similar to IMPACT 2000+, however some of the indicators are different.

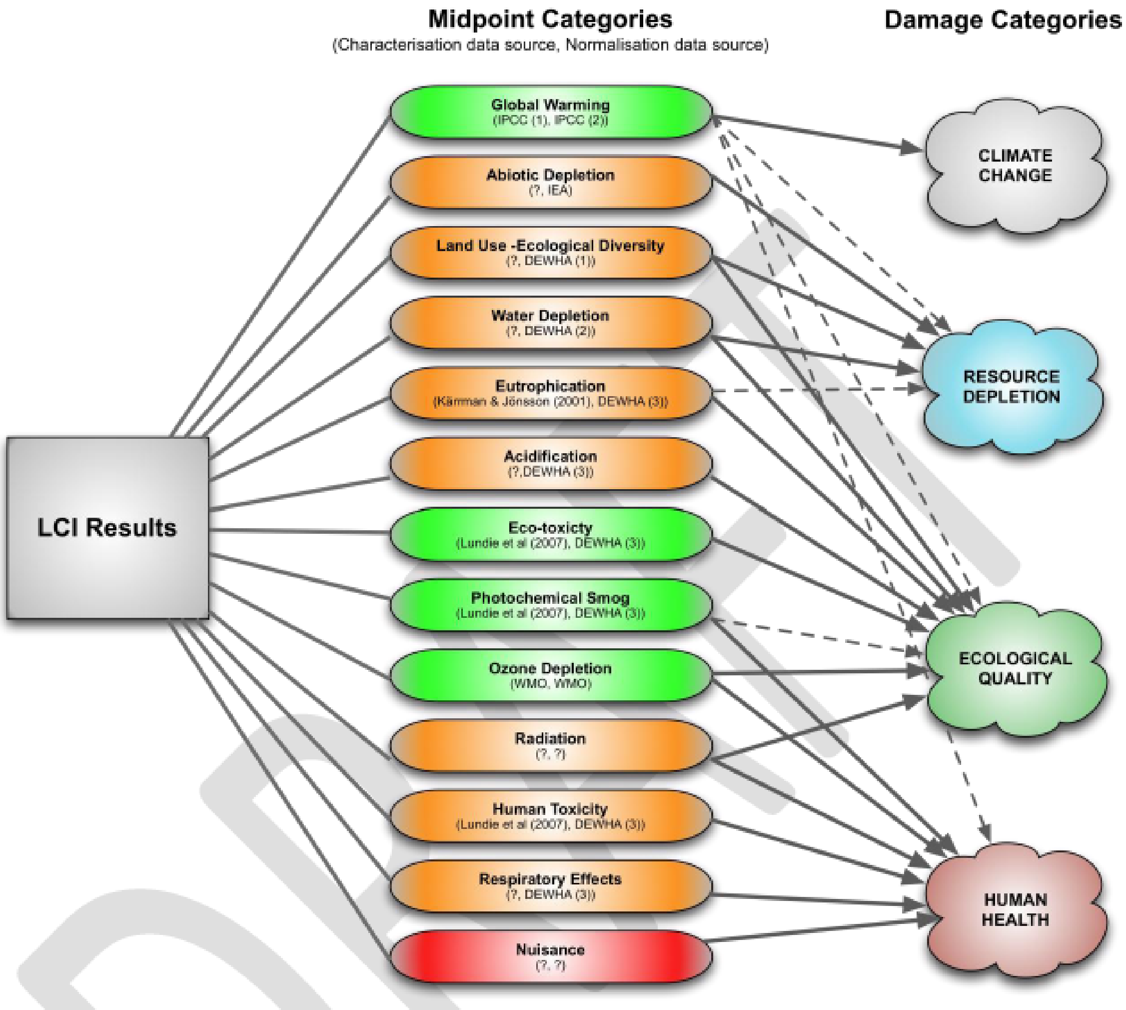


Figure 4 BPIC proposed impact assessment method for buildings.

Figure 5 compares the existing IMPACT 2002+ method to the proposed BPIC method that is being developed. The methods are similar with the exception of water use and nuisance midpoint categories which are excluded from IMPACT 2002+ (possibly due to a lack of widely accepted impact assessment methods). With this exception, IMPACT 2002+ represents a reasonable proxy of what might be expected from the BPIC method when it is finalised.

IMPACT 2002+ midpoints	Proposed BPIC midpoints	Endpoints (Identical for IMPACT2002+ and BPIC)
Global warming	Global warming	
Nonrenewable energy, mineral extraction	Abiotic depletion	
Land occupation	Land use	Climate change
Not assessed	Water depletion	
Aquatic eutrophication	Eutrophication	
Aquatic, terrestrial acidification	Acidification	Resource depletion
Aquatic, terrestrial ecotoxicity	Eco-toxicity	
Photochemical oxidation	Photochemical smog	
Ozone depletion	Ozone depletion	Ecological quality
Ionizing radiation	Radiation	
Human toxicity	Human toxicity	
Respiratory effects	Respiratory effects	Human health
Not assessed	Nuisance	

Figure 5 IMPACT 2002+ compared to the proposed BPIC impact assessment method.

To test possible results from the BPIC method, IMPACT 2002+ has been used as a proxy method to undertake a basic characterisation to be used for educative purposes (not study conclusions). The method has been applied in the form published by Jolliet et al. (Jolliet, Margni et al. 2003), assuming an equal weighting case (refer Section 10.4).

As the impact assessment method proposed involves weighting, it is arguably not compliant with ISO14044:2006, however is included as a trial exercise to contrast results with those of the core indicators described in Table 5. Results are not use to draw conclusions.

6 Methodology

LCA as defined by the ISO14040 (2006) series of standards forms the fundamental methodology for comparing the building construction types described in Section 3. The key elements of the LCA methodology are summarised in Appendix A.

In addition to the basic LCA methodology, specific methods have been used in the study to develop inventory data for building material quantities and energy consumption over the life of the building. These methods are described in the respective sub-sections of the Life Cycle Inventory (Section 7).

7 Life Cycle Inventory

7.1 Material quantities

Material quantities for the house considered are based on drawings provided by the HIA for their standard house design. The design has been developed by the HIA for benchmarking purposes, typically related to building cost. The model was selected as it represents a well considered definition of a typical Australian 3 bedroom home.

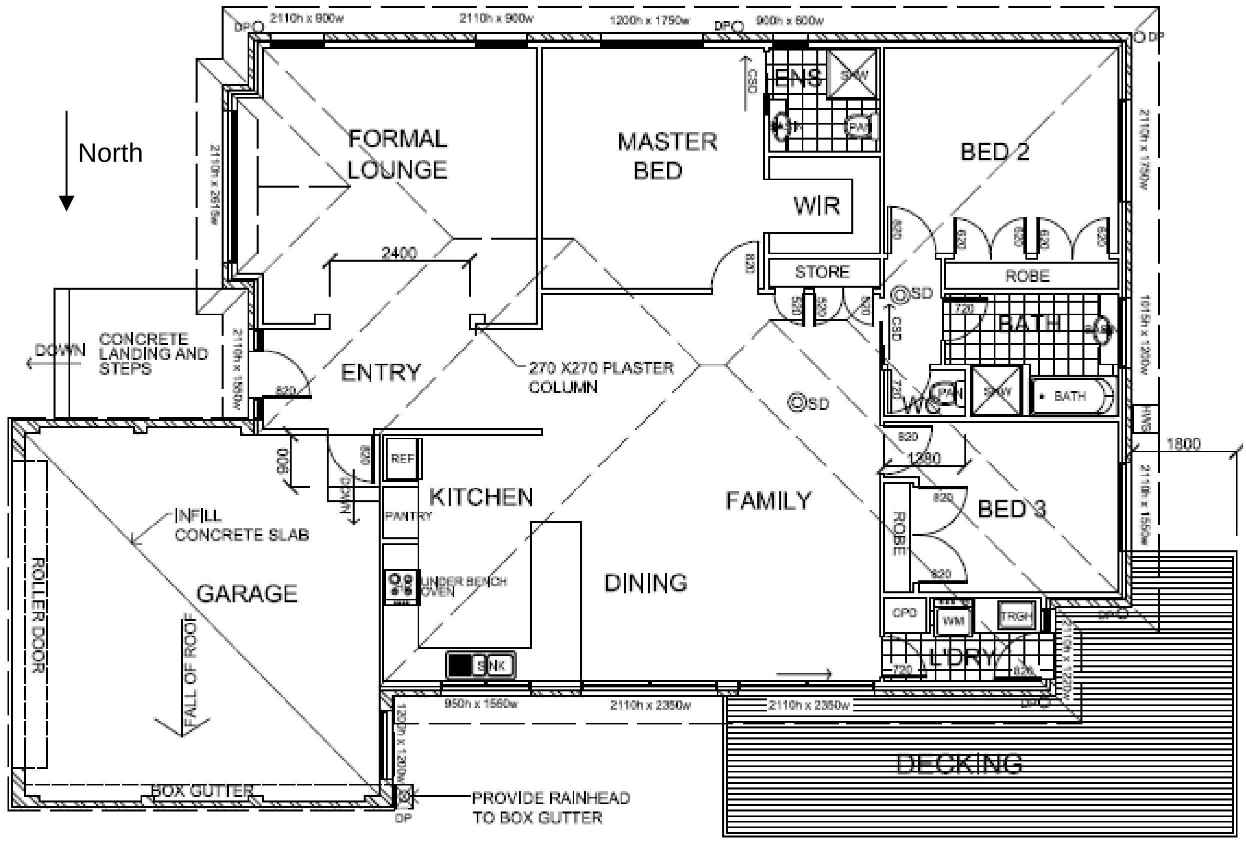


Figure 6 Floor plan of house considered (decking and landings excluded from calculations).

Construction types were developed for the house design shown in Figure 6 such that the same essential building function was delivered. Windows were kept as is and basic floorplan layout was un-modified.

A detailed definition of the essential element of each construction type is shown in Table 6.

Table 6 Construction types defined.

Construction	Floor system	Exterior wall system	Roof system	Interior walls	Window, doors system
a	**Elevated floor** Concrete posts Concrete post foundations Hardwood bearers and joists (0.45m spacing) 19mm particleboard floor Strip footing and reinforcement for brick veneer 0.6m subfloor height Concrete slab to garage	**Brick veneer** Softwood plates, studs and noggings (0.6m spacing) Bricks Mortar Plasterboard sheet Dampcourse etc	**Concrete tile** Softwood rafters, ceiling joists etc, Hardwood battens, Sarking, Concrete tiles, Fibre-cement eaves **Steeldeck to garage** Steeldeck Softwood rafters, ceiling joists etc Sarking	Softwood plates, studs and noggings (0.6m spacing) Plasterboard sheet	Hardwood frame 6.38mm Glass Hardwood exterior doors Particleboard interior doors Steel sheet garage door
b	**Concrete slab** 110mm slab Membrane Beams Reinforcing mesh	**Brick veneer** Softwood plates, studs and noggings (0.6m spacing) Bricks Mortar Plasterboard sheet Dampcourse etc	**Concrete tile** Softwood rafters, ceiling joists etc, Hardwood battens, Sarking, Concrete tiles, Fibre-cement eaves **Steeldeck to garage** Steeldeck Softwood rafters, ceiling joists etc Sarking	Softwood plates, studs and noggings (0.6m spacing) Plasterboard sheet	Hardwood frame 6.38mm Glass Hardwood exterior doors Particleboard interior doors Steel sheet garage door
c	**Elevated floor** Concrete posts Concrete post foundations Steel bearers and joists (0.45m spacing) 19mm particleboard floor Strip footing and reinforcement for brick veneer 0.6m subfloor height Concrete slab to garage	**Brick veneer** Steel plates, studs and noggings (0.6m spacing) Bricks Mortar Plasterboard sheet Dampcourse etc	**Concrete tile** Steel rafters, ceiling joists etc, battens, Sarking, Concrete tiles, Fibre-cement eaves **Steeldeck to garage** Steeldeck Steel rafters, ceiling joists etc Sarking	Steel plates, studs and noggings (0.6m spacing) Plasterboard sheet	Hardwood frame 6.38mm Glass Hardwood exterior doors Particleboard interior doors Steel sheet garage door
d	**Concrete slab** 110mm slab Membrane Beams Reinforcing mesh	**Brick veneer** Steel plates, studs and noggings (0.6m spacing) Bricks Mortar Plasterboard sheet Dampcourse etc	**Concrete tile** Steel rafters, ceiling joists etc, battens, Sarking, Concrete tiles, Fibre-cement eaves **Steeldeck to garage** Steeldeck Steel rafters, ceiling joists etc Sarking	Steel plates, studs and noggings (0.6m spacing) Plasterboard sheet	Hardwood frame 6.38mm Glass Hardwood exterior doors Particleboard interior doors Steel sheet garage door
e	**Elevated floor** Concrete posts Concrete post foundations Hardwood bearers and joists (0.45m spacing) 19mm particleboard floor 0.6m subfloor height Insulated (polystyrene) fibre-cement enclosure of subfloor Concrete slab to garage	**Timber weatherboard** Softwood plates, studs and noggings (0.6m spacing) Weatherboards Plasterboard sheet Dampcourse etc	**Concrete tile** Softwood rafters, ceiling joists etc, Hardwood battens, Sarking, Concrete tiles, Fibre-cement eaves **Steeldeck to garage** Steeldeck Softwood rafters, ceiling joists etc Sarking	Softwood plates, studs and noggings (0.6m spacing) Plasterboard sheet	Hardwood frame 6.38mm Glass Hardwood exterior doors Particleboard interior doors Steel sheet garage door

Table 7 Calculated areas and distances for the base design.

	dim	unit	
Garage area	43.5	m2	
Concrete landing and step area	9.3	m2	
Formal lounge area	26.0	m2	
Entry area	7.6	m2	
Kitchen area	9.6	m2	
Dining+Family area	40.5	m2	
Master bedroom area	18.4	m2	
ENS+WIR (with store) area	9.1	m2	
Bedroom 2 (with robe) area	18.6	m2	
Bath+WC area	9.7	m2	
Bedroom 3 (with robe) area	13.8	m2	
L'Dry area	4.8	m2	
Decking area	27.5	m2	
total area	238.4	m2	
total excl deck,landing area	**201.6**	**m2**	<- Functional area of building
Total tiled roof area (plan)	181.7	m2	
Total steeldeck roof area	43.5	m2	
External wall perimeter length	65.7	m	
External wall area (excl windows)	106.8	m2	
Internal wall area	121.2	m2	
Window area	34.5	m2	
External door area (incl garage)	14.5	m2	
Subfloor perimeter	53.1	m	
Wall heights	2.4	m	
Roofspace volume estimate	290.3	m3	
Subfloor space volume estimate	126.5	m3	

Material quantities for the house have been developed from calculated wall, window, floor and roof areas (Table 7) and standard quantity factors based on Lawson (1996) which have been adjusted to accommodate more realistic quantities for foundation systems, elevated floor systems and to recognise contemporary building material sizes (Appendix C). This technique is similar to that applied by Maddox (2003), however an additional material quantity benchmarking exercise was also undertaken.

A weakness when using area based estimates to determine material quantities is that there is a risk that complexities in building design will not be properly accounted for, or that scalar differences will lead to estimates being inaccurate. The alternative is to complete a detailed structural design of all wall, roof and floor in plan and elevation and develop quantities from these, as in Lippke (2004).

In this study it was felt that an area based approach would be sufficient to achieve a reasonable degree of accuracy and that such an approach would enforce a high degree of consistency in material quantity estimates across construction types. As a further check of material quantities developed, benchmark quantity data from various sources was used, and where necessary adjustments made. The final benchmark quantity assessment is shown in Appendix D.

Table 8 shows the major building materials considered in the basic building bill of quantities. Other items such as windows, sarking, insulation, door hardware, doors, dampcourse and concrete membrane are also included in the model developed. Sub-assembly material quantities per unit area, per unit distance, or per unit are detailed in Appendix C.

Table 8 Bill of major material quantities (windows included but not shown) for the basic design.

Summary of material quantities (per house)	unit	a	b	c	d	e
Hardwood (battens, joists, bearers, lintels)	m3	4.0	1.7	0.6	0.6	4.1
Softwood frame	m3	7.0	7.0	0.0	0.0	7.0
Softwood weatherboard	m3	0.0	0.0	0.0	0.0	2.6
Framing steel	kg	0.0	0.0	4790.9	2673.0	0.0
Reinforcing steel (concrete)	kg	336.0	1000.9	336.0	1000.9	215.8
Structural steel (lintels, beams)	kg	169.9	169.9	169.9	169.9	0.0
Sheet steel (roof)	kg	281.6	281.6	281.6	281.6	281.6
Concrete	m3	12.4	33.2	12.4	33.2	8.5
Mortar	kg	4068.0	2682.6	4068.0	2682.6	0.0
Brick	units	7132.2	5234.4	7132.2	5234.4	0.0
Particleboard	m2	158.2	0.0	158.2	0.0	158.2
Plasterboard	m2	615.4	615.4	615.4	615.4	615.4
Tiles	kg	9445.8	9445.8	9445.8	9445.8	9445.8
Fibre cement sheet	m2	23.6	23.6	23.6	23.6	23.6
Plate glass (6.38mm)	m2	34.5	34.5	34.5	34.5	34.5
Other	kg	298.3	333.0	298.3	333.0	309.7

Summary of material quantities (per m2)	unit	a	b	c	d	e
Hardwood	m3	0.020	0.009	0.003	0.003	0.020
Softwood frame	m3	0.035	0.035	0.000	0.000	0.035
Softwood weatherboard	m3	0.000	0.000	0.000	0.000	0.013
Framing steel	kg	0.000	0.000	23.763	13.258	0.000
Reinforcing steel (concrete)	kg	1.667	4.965	1.667	4.965	1.070
Structural steel (lintels, beams)	kg	0.843	0.843	0.843	0.843	0.000
Sheet steel (roof)	kg	1.397	1.397	1.397	1.397	1.397
Concrete	m3	0.062	0.165	0.062	0.165	0.042
Mortar	kg	20.177	13.305	20.177	13.305	0.000
Brick	units	35.375	25.962	35.375	25.962	0.000
Particleboard	m2	0.784	0.000	0.784	0.000	0.784
Plasterboard	m2	3.052	3.052	3.052	3.052	3.052
Tiles	kg	46.851	46.851	46.851	46.851	46.851
Fibre cement sheet	m2	0.117	0.117	0.117	0.117	0.117
Plate glass (6.38mm)	m2	0.171	0.171	0.171	0.171	0.171
Other	kg	1.480	1.652	1.480	1.652	1.536

7.2 Building life

Building life has been assumed to be **50 years**. This assumption is consistent with other studies (refer Section 4) as well as Australian Building Codes Board guidance (ABCB 2006).

Building life can be difficult to forecast, so the assumption is also tested as a sensitivity study under Section 10.2.

7.3 Key materials incorporated

7.3.1 Timber

The timber inventory used in this study has been developed by the CSIRO in accordance with the AusLCI guidelines for inventory development. The inventory has not yet been released, nor has it been included in the AusLCI at the time of report writing.

The LCI has been structured around a range of timber products, however only three are used in this study, Sawn hardwood, Sawn softwood and Particleboard. These inventories incorporate unit processes that extend from the primary growing of trees through harvesting, processing and final delivery. Figure 7 shows a sample of the inventory structure for sawn softwood when assessed for global warming.

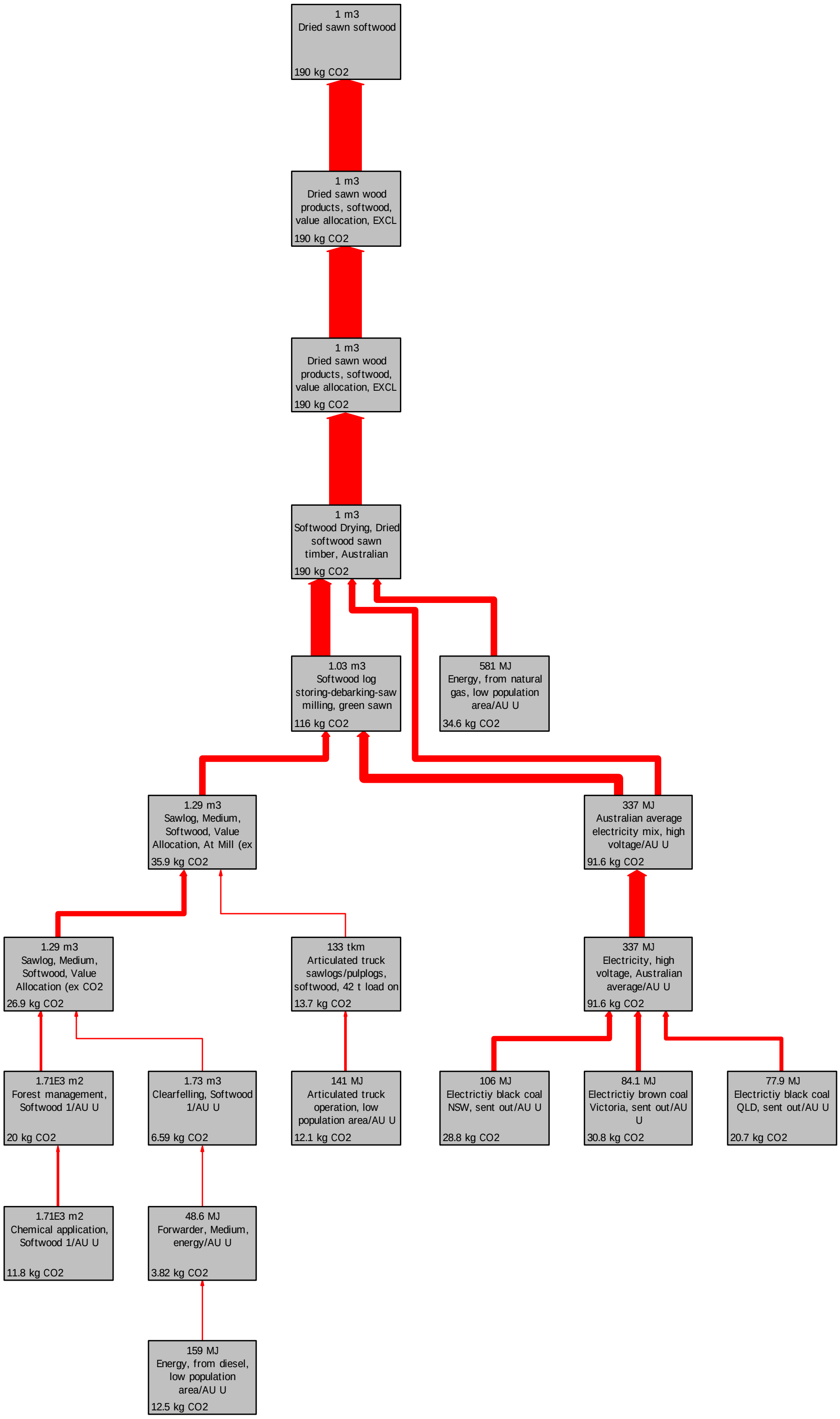


Figure 7 Sawn softwood - Global warming impacts (5.7% cutoff shown).

The inventory is comprehensive, and incorporates data needed to assess each of the indicators used in this study.

Table 9 describes a simple characterisation of the of 1 cubic meter of sawn timber product using the CSIRO developed inventory.

Table 9 Impacts for 1m3 timber product using the CSIRO developed inventory and the impact assessment method used in this study.

Impact category	Unit	AusLCI Compliant - Softwood		AusLCI Compliant - Hardwood
Global Warming	kg CO2	190.0		456.9
Photochemical oxidation	kg C2H4	0.541		0.531
Eutrophication	kg PO4--- eq	0.318		0.246
Land use	Ha a	1.86E-01		2.25E-02
Water Use	KL H2O	380.5		1040.4
Solid waste	kg	3.8		6.4
Resource depletion	MJ Surplus	167.433		254.561
Embodied energy LHV	MJ LHV	4716.8		5670.4

Agricultural process flows considered in the softwood LCI are based on a survey of forest growers from four softwood forest regions around Australia (WA, Green Triangle, NSW Southern Highlands and SE Queensland. Allocation of forestry inputs including stand establishment, management, thinning and clearfelling (but excluding haulage to mill) to products harvested (Large, medium and small sawlogs, pulplogs, logs for in-field woodchips and other logs) is based on the economic value. The inventory also assumes the forest is in a steady state (i.e. does not include new plantings and assumes management and production are constant).

Process flows for hardwood from native forest are treated in a similar fashion to softwood, however survey data is from native forest managers from 3 regions around Australia (Tasmania - Derwent region, Victorian Central Highlands and North East New South Wales).

Water flows for both inventories are based on the difference in water consumption between the forest and an alternative use. For softwood timber, the water consumption is based on the difference in water use between a plantation forest and pasture. For hardwood timber, the water consumption is based on the difference in water use between a native forest available for wood production and one reserved for conservation.

The inventory used does not include carbon sequestered in wood products (softwood and hardwood) during the use phase of timber product life. The assumption applied here is that the construction types considered are not incremental additions to the building stock, but are replacing existing buildings in a steady state population (this assumption is tested as a sensitivity under Section 10.3). As a result of this assumption, no ‘credit’ is allocated to timber products for storing carbon in buildings (as discussed in Section 5.2.1).

7.3.2 Steel

Two basic steel LCI datasets are used in this study, as follows:

i) Steel sheet, galvanised (framing, roofing)
ii) Steel structural (lintels, flanged beams)
iii) Steel reinforcing bar (concrete reinforcement)

The fundamental inventory for steel production for galvanised sheet steel components and structural components (excluding reinforcing bar) is based on the structural steel LCI published in the Australian LCI Database. The LCI is representative of generic steel production in Australia and was compiled by BHP Steel. An extract of the LCI is shown below:

> *“Values based on data from a range of sources for the time periods of 1994 to 1996. The annual production values from the production processes used in the aggregation are:*
> *· 830kt/y heavy structural steel;*
> *· 1600kt/y light structural steel;*
> *· 480kt/y steel plate;*
> *· 1050kt/y EAF steel;*
> *· 5kt/y House framing steel;*

· 480kt/y Galvanised flat steel;
· 440kt/y ZINCALUME flat; and
· 260 kt/y COLORBOND flat.

The data represent LCI values for average steel products made in Australia. The values are an aggregation of a range of steel products and are based on full life cycle inventories completed by BHP Research on a wide range of steel products in a number of applications. Data come from a BHP Research LCA Factsheet "Life Cycle Inventory Values for Australian steel products", restricted circulation. Data used with the permission of BHP Research. Data in this inventory should be considered as relatively old and possibly out of date (ie. valid for 1997) as the Australian steel industry has changed significantly during 1997 and 1999 (Dr L. Wibberley, BHP Research, pers.comm, 03/1999).
Key assumptions used are:
a) the values do not include stainless steel which is no longer produced in Australia;
b) the values do not include tinplate or steel used for packaging;
c) the values do not include imported or exported raw steel;
d) the values aggregate both steel made from scrap (recycled) steel and from iron ore, in proportion to their contribution to total production
e) the values incorporate a wide range of products and manufacturing processes. The values for products with little processing (eg. plate) are lower than values for products with more processing (roof sheeting). Similarly, the actual values for recycled steel are lower than those for steel made from raw materials;;
f) the values are generic values suitable for broad studies." Australian LCI Database (2005)

The uncoated steel is then added to a galvanising LCI from the IVAM database, based on European practices in 2003.

The reinforcing steel inventory assumes steel is predominantly derived from the Electric Arc Furnace (EAF), and was compiled from a mix of Australian sources by Tim Grant in 2004.

The steel inventory properties per kg are compared to an independent Australian report "A Life Cycle Perspective on Steel Building Materials" (Strezov and Herbertson 2007) in Table 10. Galvanised sheet steel impacts are generally lower than those of Strezov and Herbertson, and reinforcing steel impacts are comparable.

Table 10 Study steel (1kg) impacts compared to Strezov and Herbertson (2004).

		Galvanised steel		Reinforcing steel	
Impact category	Unit	This study	Strezov and Herbertson (2007)	This study	Strezov and Herbertson (2007)
Global Warming	kg CO2e	2.3	3.6	1.1	1.1
Photochemical oxidation	kg C2H4	0.003	Not assessed	0.000	Not assessed
Eutrophication	kg PO4--- eq	0.002	Not assessed	0.000	Not assessed
Land use	Ha a	6.76E-07	Not assessed	3.52E-07	Not assessed
Water Use	KL H2O	0.0035	0.0065	0.0016	0.0013
Solid waste	kg	0.3	0.15	0.1	0.12
Resource depletion	MJ Surplus	2.206	Not assessed	0.791	Not assessed
Cumulative Energy Demand	MJ LHV	27.8	43	12.0	12

7.3.3 Concrete

Concrete LCI data is sourced from the Australian LCI Database based on a 20MPa mixture as follows:
1 kg concrete comprises:

Portland cement: 83.1g
Sand: 350g
Aggregate: 740g
Blast furnace slag: 16g
Water: 0.09l

The inventory was developed 1996/7 and is based on CSR Readymix data believed to be generally appropriate for Australia. Table 11 compares the AUPLCI (2009) to a U.S. study of concrete manufacture (Prusinski, Marceau et al. 2005).

Table 11 Australian LCI Database concrete (1m3) compared to Prusinski et al (2005).

Impact category	Unit	Australian LCI Database	Prusinski (2005)
Global Warming	kg CO2	288.3	228.0
Photochemical oxidation	kg C2H4	0.067	Not assessed
Eutrophication	kg PO4--- eq	0.113	Not assessed
Land use	Ha a	1.24E-05	Not assessed
Water Use	KL H2O	8.0	Not assessed
Solid waste	kg	220.2	Not assessed
Resource depletion	MJ Surplus	214.719	Not assessed
Embodied energy LHV	MJ LHV	2676.8	1684.0

7.3.4 Brick

The brick LCI used in this study is from the AUPLCI (2009) and is based on an EcoInvent LCI for clay brick that has been modified to accept Australian energy sources for electricity and natural gas. Following the release of a recent LCA describing Australian brick production (Rouwette 2010) the inventory was updated to achieve a similar global warming result under impact assessment. The adjustment was achieved by changing the fuel mix (gas/electricity) used in the brick making process based on the Rouwette (2010) report, and by reducing fugitive CO2 emissions.

Table 12 compares the impacts of the study inventory to other reference publications (Maddox and Nunn 2003; Koroneos and Dompros 2007). An additional, and very recent LCA has also recently been completed on Australian bricks that focussed on global warming and embodied energy (Rouwette 2010) – global warming result shown estimates brick mass at 3kg.

Table 12 1 tonne of bricks in this study compared to reference publications.

Impact category	Unit	This study	Maddox et al. (2003)	Koroneos et al. (2007)	Green Magazine (2010) - "Think Brick" study.
Global Warming	kg CO2	203.3	200.0	220.7	203.3
Photochemical oxidation	kg C2H4	0.076	Not assessed	0.092	Not assessed
Eutrophication	kg PO4--- eq	0.076	Not assessed	0.043	Not assessed
Land use	Ha a	3.75E-05	Not assessed	Not assessed	Not assessed
Water Use	KL H2O	0.2	0.150	Not assessed	Not assessed
Solid waste	kg	3.3	Not assessed	2.788	Not assessed
Resource depletion	MJ Surplus	242.708	Not assessed	Not assessed	Not assessed
Embodied energy LHV	MJ LHV	2945.8	2940.0	Not assessed	3166.7

7.3.5 Other materials

Other materials included in the inventory are listed, along with sources, in Table 13. In general, these materials are not significant divers of life cycle impacts versus the others described above.

Table 13 Other materials included.

Material	Inventory source	Comment/modifications
Sarking	Australian LCI datasets	Includes aluminium production and rolling.
Fibreglass insulation	Australian LCI datasets	Assumed desnity 6.92kg/m3
Plate glass	Ecoinvent	Adapted to incorporate Australian energy.
Aluminium extrusion	Australian LCI datasets	Includes aluminium production and extrustion transformation.
Acrylic paint	Australian LCI datasets	
Fibrecement sheet	Ecoinvent	Adapted to incorporate Australian energy.
Polystyrene insulation	Ecoinvent	
Mortar	Australian LCI datasets	Sand, cement, lime, blending energy included.
Plasterboard	IVAM	Model for the production of plasterboard modified to incorporate Australian energy sources. Incorporates 0.6mm paper layers and plaster.
Aluminium flashing	Australian LCI datasets	Includes aluminium production and rolling.
Polethylene dpc and membrane	Australian LCI datasets	LDPE flim used as a proxy.

7.4 Construction

Little detailed information exists regarding residential building construction impacts in Australia. An estimate has been developed based on inbound transport of materials – assumed to be 50km via rigid truck for all constituent materials, from regional store to the construction site. Onsite fabrication impacts are assumed to be minimal for all construction types (labour is excluded).

In order to sense check this assumption, total energy results (embodied energy of transport) were compared to Cole (1998). Cole's results are shown in Figure 8.

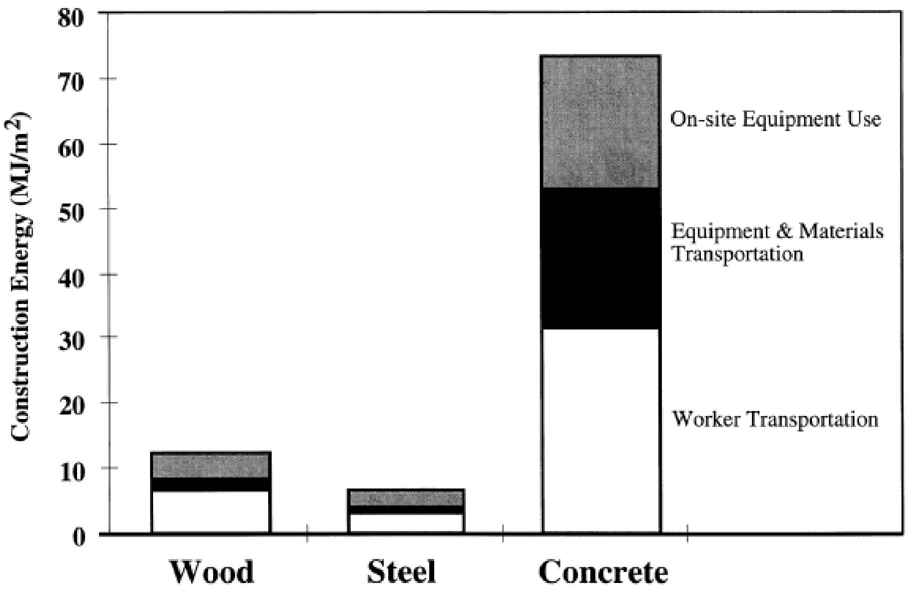


Figure 8 Construction energy for different structural types (Cole 1998)

Figure 9 illustrates Cole's results on the same scale as the construction assumptions used in this study. Overall the study assumptions are of a similar scale to Cole, and behave in a directionally similar manner. Differences in energy requirements per construction type in this study are driven by the mass of building constituent materials (lighter construction types have lower construction energies).

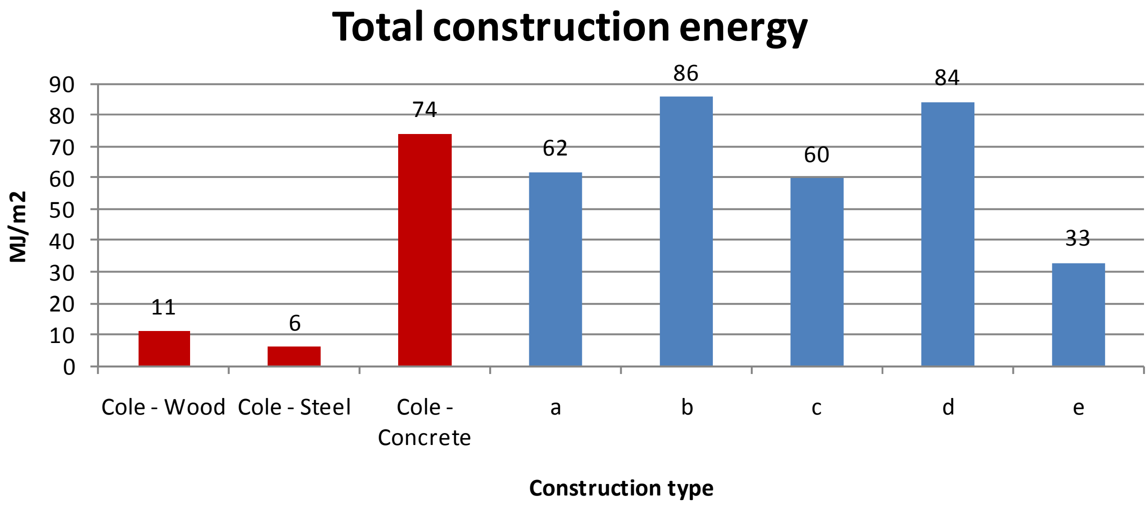


Figure 9 Construction energy assumptions for each construction type compared to Cole (1998).

Trucking impacts are calculated using the Rigid Truck inventory, based on Australian average practice, published in the AUPLCI (2009).

7.5 Building operation

Each construction type assessed was modelled using the AccuRate energy simulation package by Hearne Scientific Software (V1.1.4.1). Houses were assessed for a star rating then adjusted by adding energy efficiency enhancements as necessary in order to achieve a star rating of 5 stars in each of the climate zones considered (Melbourne, Sydney, Brisbane).

Appendix E contains the results of the AccuRate simulations for each construction type and climate. Given the difficulty in achieving an exact 5 star rating, results were adjusted slightly to achieve an exact 5 star rating by determining the proportion of heating load in percentage terms then applying this ratio to the 5 star benchmark. In this manner, all construction types achieve the same total heating and cooling load, while maintaining unique heating and cooling balances.

When adding efficiency measures, a hierarchy that attempts to minimise incremental embodied energy was applied as follows:

1) add insulation (glass fibre)
2) add shading
3) add solar glass
4) add double or advanced (argon filled) glazing.

Enhancements required to achieve the 5 star rating for each construction type are shown in Table 14.

Table 14 Design alterations required to achieve 5 star rating in respective climate zone.

		Area (m2)	a	b	c	d	e
Melbourne							
	Ceiling insulation	201.62	R3	R3	R3	R3	R4
	External walls insulation	119.58	R1	R1	R1	R1	R1.5
	Floor insulation	158.15	no	no	no	no	no
	Canvas awning formal,bed2&3 only	12.48	yes	yes	yes	yes	yes
	Pergola to north windows	17.1	yes	yes	yes	yes	yes
	Double glaze kitchen/dining/family only (3/6/4low e)	11.39	no	no	no	no	no
	Double glaze formal only (3/6/4low e)	9.32	no	no	no	no	no
Sydney							
	Ceiling insulation	201.62	R4	R4	R4	R4	R4
	External walls insulation	119.58	R2.0	R1	R2.0	R1	R2.0
	Floor insulation	158.15	no	no	no	no	no
	Canvas awning formal,bed2&3 only	12.48	yes	yes	yes	yes	yes
	Pergola to north windows	17.10	yes	yes	yes	yes	yes
	Pergola to formal only	9.00	no	no	no	no	yes
	Pergola to bed 2, bed 3 only	4.80	no	no	no	no	no
	Solar glass (low e) formal,bed2,bed3 only	12.48	yes	no	no	no	yes
	Solar glass (low e) kitchen/dining/family only	11.39	yes	no	yes	no	yes
	Double glaze all (3/6/4low e)	32.97	no	no	no	no	no
Brisbane							
	Ceiling insulation	201.62	R4	R3.5	R4	R3.5	R4
	External walls insulation	119.58	R2.0	R1.5	R2.0	R1.5	R2.0
	Canvas awning formal,bed2&3 only	12.48	yes	yes	yes	yes	yes
	Pergola to north windows	17.1	yes	yes	yes	yes	yes
	Pergola to formal only	9.00	yes	no	yes	no	yes
	Pergola to bed 2, bed 3 only	4.80	yes	no	yes	no	yes
	Solar glass (low e) to formal,bed2,bed3 only	12.48	yes	yes	yes	yes	yes
	Solar glass (low e) kitchen/dining/family only	11.39	yes	no	yes	no	yes
	Double glaze (3/6/4low e) all	32.97	no	no	no	no	no
	Double glaze (high eff, 3/12a/4low e) all	32.97	no	no	no	no	no
	Double glaze (high eff, 3/12a/4low e) kitchen/dining/family only	11.39	no	no	no	no	no
	Double glaze (high eff, 3/12a/4low e) formal only	5.52	no	no	no	no	no
	Double glaze (high eff, 3/12a/4low e) bed2, bed 3 only	6.96	no	no	no	no	no

Accross the board assumptions (unless stated otherwise):

Glass: 6.38mm lam in single glaze
Reflective sarking to roof and walls
Weatherstrips to all windows and doors
Internal wall to kitchen and laundry match external wall insulation level.

7.5.1 Energy sources for heating and cooling

In order to translate energy consumption during building operation into environmental impacts, assumptions regarding the heating and cooling systems employed are required.

For heating it is assumed that a natural gas fired heater system with a thermal efficiency of 70% is used.

For cooling it is assumed that an electric refrigerative cooling system with an Energy Efficiency Ratio of 3.5 (Power out/Power in) plus an additional 20% loss in ducting.

Carbon impacts per unit of energy consumption are based on the Eastern Australian electricity grid and the Australian natural gas supply, as provided in the Australian LCI database.

Table 15 Global warming impacts for operational energy sources.

	Energy	Emission (kg CO2e)
Electricity	1kWh	1.11
Natural gas	1MJ	0.069

7.6 Maintenance

Maintenance requirements for the constructions have been estimated based on assumed replacement rates. Table 16 describes the estimated replacement rates for key components. In general, replacement frequencies are equal to or higher than technical design lives (Howard, Burgess et al. 2007; NAHB 2007) quoted in the literature. Accrual of maintenance impact is assumed to occur linearly from the commencement of house operation (as opposed to discrete intervals), thereby avoiding interval truncation errors.

Table 16 Maintenance assumptions.

Component	Replacement interval
External timber cladding (type e only)	50 years
Internal walls	100 years
Concrete roof tiles	100 years
Windows	45 years
Doors	25 years
Exterior painting	10 years
Interior painting (small area for brick)	10 years

Disposal of components replaced is assumed to be to landfill.

7.7 End of life

At end-of-life the building materials are assumed to be disposed of to either a recycling process or a landfill process. Recycling recovery rates are summarised in Table 17 and are based on anecdotal survey evidence described in Crowther (2000) for commercial buildings in Australia. Residential building data quoted by Crowther assumed higher recycling and reuse rates than those described below, however data was considered to be of a lesser quality.

Table 17 Recycling assumptions at end of building life.

Material	Recovery rate	Reprocessing	Substitution material	Substitution Quantity
Aluminium	90%	Collect, remelt	Aluminium products	0.95kg/1kg recovered
Cement tiles	70%	Collect, crush	Quarried stone aggregates	0.9kg/1kg recovered
Concrete	70%	Collect, crush	Quarried stone aggregates	0.99kg/1kg recovered
Steel - structure	95%	Collect, remelt EAF	Steel for reinforcing	0.95kg/1kg recovered
Steel - reinforcing	50%	Collect, remelt EAF	None*	NA
Timber	50%	Collect, remill	Sawn product	0.9kg/1kg recovered
Brick	75%	Collect, crush	Quarried stone aggregates	0.9kg/1kg recovered

* Credit for recycled content incorporated into impact of reinforcing steel production.

When materials are recycled, impacts associated with recovery and reprocessing are included, less a ‘credit’ for avoided virgin product. System expansion in both a closed loop (metals, plastics, glass) and an open loop (ceramics, timber) are used to model recycling unit processes. Open loop cycles are required for those materials that experience significant degradation of material properties during reprocessing. In these instances, the system boundary is expanded up to the first use of the recycled material and cut-off at this point.

For reinforcing steel, which contains a high percentage of recycled steel, no avoided product is assumed. This assumption avoids double counting benefits associated with the use of recycled content which is already accounted for in the reinforcing steel production inventory.

An alternative treatment of steel recycling based on the avoided impacts being equivalent to the world production of EAF and BOF steel is also explored as a sensitivity study in Section 10.5.

7.7.1 Landfill processes employed

As organic matter breaks down in landfill both biogenic carbon dioxide (CO_2), methane (CH_4) and other gasses are emitted. Of these, methane is the most important from a global warming perspective because it has a high global warming potential (21-25 times that of CO_2). Biogenic CO_2 is not considered a source of anthropogenic global warming, so is not accounted for directly.

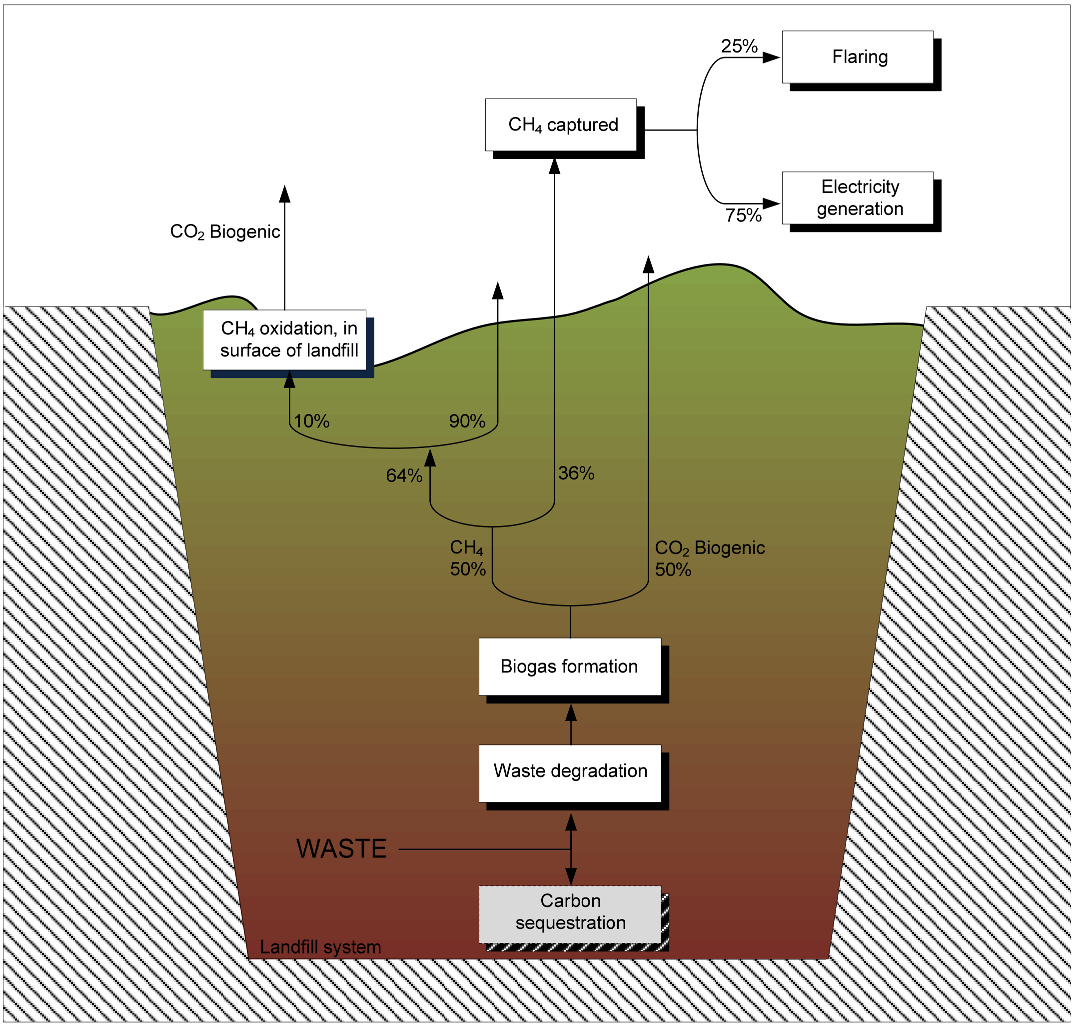
Determination of the amount of methane generated by timber decay in landfill can be undertaken in a number of ways. In this study impacts are based on a study undertaken by the US EPA (US EPA 2006) which assessed actual decomposition rates of various products disposed of to landfill.

Methane generated from the degradation of organic waste has been determined theoretically in this study using a methodology published by the U.S. EPA (US EPA 2006). The methodology assumes that 12% of the organic carbon in waste timber will be converted into methane (figure for “branches”

(US EPA 2006) used as a proxy for timber). Organic carbon content for softwood is assumed to be 445kg C per m3 and 573kg C per m3 for hardwood (from the Timber LCI documentation).

36% of the methane generated is then assumed to be captured under the cap of the landfill and is either flared or used for electricity generation (Hyder, 2006). The remaining 64% is assumed to pass through the surface of the landfill where 10% is oxidised and the remainder is emitted to the atmosphere. A diagrammatic representation of this model is shown in Figure 10.

Figure 10: Treatment of timber waste in landfill.



Of the original carbon content, the US EPA (2006) study states that 77% (again the proxy of timber "branches" is selected) is stored in the landfill. Term of storage is uncertain however, greater than 100 years is assumed in this study.

Further work has been undertaken by Ximenes and Gardner et al. (2008) which adds further weight to the assumption that carbon within timber products is stored in landfill for considerable periods of time. Ximenes and Gardner describe carbon decomposition rates of between 17-18% equating to storage rates of 82-83% for timber products disposed of to landfills in the Sydney area (Ximenes, Gardner et al. 2008). Ximenes and Gardner make a compelling argument for increasing assumptions regarding the storage of carbon in landfill, however analysis does not extend to the exact amount of methane creation from timber decomposition:

> "It is important to note that there is currently insufficient field evidence to determine what proportion of carbon from wood products potentially lost through degradation is emitted as carbon dioxide and as methane."(Ximenes, Gardner et al. 2008)

This limitation means that it is not possible to take the result and translate it into a completely new model for timber degradation (although it is possible to combine results with other work such as US EPA. Refer Section 10.3).

The US EPA method was selected as the waste treatment method used in this study as it represents a well argued and empirically based assessment of organic material behaviour in landfill.

7.7.1.1 Alternative approaches

An alternative to the US EPA approach used here, would be the methodology described by the IPCC methodology as interpreted in Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks – Waste (Dept. of Climate Change 2007). This methodology assumes that all timber has a certain carbon content and that a given proportion of this carbon content will degrade anaerobically to form methane. Equation 1 describes how the greenhouse gas emission is determined under the methodology.

Equation 1 Calculation of global warming emissions from landfill under the IPCC as described in Dept. of Climate Change (2007).

$$\text{GHG Emission from Landfill} = [((Q \times DOC \times DOC_F \times F_1 \times 16/12) - R) \times (1 - OX)] \times 21$$

where :

$\text{Q} = $ Quantity of municipal solid waste expressed in tonnes

$\text{DOC} = $ Degradable Organic Carbon expressed as a proportion of the particular waste type. 0.43 used for wood.

$\text{DOC}_F = $ Fraction of degradable organic carbon dissimilated for the waste type produced with a default value of 0.5.

$\text{F}_1 = $ Methane fraction of landfill gas which has a default value of 0.50

$\text{R} = $ Methane emissions captured from landfill (0.36 assumed as described for USEPA method).

$\text{OX} = $ Oxidation factor which has a default value of 0.1 for covered, well - managed landfills.

Given the prominent nature of the IPCC method in Australian carbon accounting (it is the prescribed method of determining emissions by the Federal Department of Climate Change) it has been assessed as a sensitivity study in Section 10.3.

7.7.1.2 Storage of carbon in timber in landfill

Both of the above assessment methods infer that a significant proportion of carbon within timber products remains within the landfill for an extended period of time. In this study this 'left over' carbon is assumed to be stored for at least 100 years (the timeframe over which the global warming assessment is assumed to be made) and therefore is accounted for as a global warming 'credit' in the LCA. This 'credit' (a negative global warming impact) is accrued because the biogenic carbon within the timber is considered to be stored underground for the period of the global warming assessment undertaken.[2]

A relaxation of this assumption is addressed as a sensitivity study in Section 10.3.

[2] Double counting is avoided because biogenic carbon assimilation during tree growth is not assessed as an elementary flow. Only the storage of carbon in landfill is assessed at the end of the timber product life cycle.

7.8 Elementary flows

The elementary flows resulting from the inventory described above are shown in Table 18 (only those flows that contribute more than 1% to any of the indicators assessed in this study are shown).

Table 18 Elementary flows that contribute more than 1% or more to any indicator assessed (1 functional unit shown). Other flows not shown.

			Melbourne					Sydney					Brisbane				
Substance	**Compartment**	**Unit**	**a**	**b**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**
Carbon dioxide, fossil	Air	kg	4.19E+00	4.58E+00	4.25E+00	4.60E+00	4.10E+00	3.73E+00	3.83E+00	3.79E+00	3.84E+00	3.24E+00	4.56E+00	4.75E+00	4.62E+00	4.76E+00	4.09E+00
Carbon dioxide	Air	kg	8.23E+00	8.22E+00	9.08E+00	8.72E+00	7.75E+00	2.46E+00	2.68E+00	3.32E+00	3.18E+00	2.30E+00	2.12E+00	2.25E+00	2.98E+00	2.75E+00	1.95E+00
Carbon monoxide	Air	kg	2.19E-02	1.74E-02	5.68E-02	3.66E-02	2.26E-02	1.69E-02	1.26E-02	5.19E-02	3.18E-02	1.80E-02	1.71E-02	1.25E-02	5.20E-02	3.17E-02	1.80E-02
Hexane	Air	kg	9.91E-05	9.53E-05	1.02E-04	9.71E-05	9.50E-05	2.36E-05	2.28E-05	2.68E-05	2.46E-05	2.37E-05	1.91E-05	1.72E-05	2.23E-05	1.90E-05	1.90E-05
Methane	Air	kg	2.92E-02	2.42E-02	1.35E-02	1.28E-02	3.12E-02	2.51E-02	2.00E-02	9.41E-03	8.59E-03	2.73E-02	2.60E-02	2.05E-02	1.03E-02	9.07E-03	2.79E-02
Nitrogen oxides	Air	kg	8.17E-02	7.98E-02	8.59E-02	8.21E-02	7.85E-02	2.83E-02	2.78E-02	3.25E-02	3.01E-02	2.70E-02	2.73E-02	2.62E-02	3.15E-02	2.85E-02	2.59E-02
NMVOC, non-methane volatile organic co	Air	kg	4.02E-03	4.09E-03	4.18E-03	4.17E-03	3.57E-03	1.97E-03	2.12E-03	2.14E-03	2.20E-03	1.63E-03	1.88E-03	1.99E-03	2.04E-03	2.07E-03	1.53E-03
Propylene glycol	Air	kg	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.20E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.20E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.20E-03
Sulfur dioxide	Air	kg	4.32E-03	4.48E-03	5.86E-03	5.37E-03	4.37E-03	3.96E-03	3.89E-03	5.50E-03	4.78E-03	3.69E-03	4.61E-03	4.61E-03	6.17E-03	5.51E-03	4.36E-03
VOC, volatile organic compounds	Air	kg	1.06E-03	7.41E-04	7.79E-04	5.11E-04	1.19E-03	1.06E-03	7.41E-04	7.79E-04	5.11E-04	1.19E-03	1.07E-03	7.41E-04	7.89E-04	5.11E-04	1.20E-03
Coal, 20.5 MJ per kg, in ground	Raw	kg	4.41E-01	4.97E-01	4.47E-01	4.98E-01	4.63E-01	3.84E-01	4.04E-01	3.90E-01	4.06E-01	3.57E-01	4.86E-01	5.17E-01	4.92E-01	5.19E-01	4.61E-01
Coal, 21.5 MJ per kg, in ground	Raw	kg	5.60E-01	6.24E-01	7.28E-01	7.21E-01	5.90E-01	4.85E-01	5.02E-01	6.54E-01	5.99E-01	4.51E-01	6.19E-01	6.51E-01	7.88E-01	7.47E-01	5.88E-01
Coal, brown, 8.1 MJ per kg, in ground	Raw	kg	1.38E+00	1.56E+00	1.40E+00	1.57E+00	1.45E+00	1.19E+00	1.26E+00	1.21E+00	1.26E+00	1.10E+00	1.53E+00	1.63E+00	1.55E+00	1.63E+00	1.45E+00
Gas, natural, 35.9 MJ per m3, in ground	Raw	m3	3.55E+00	3.37E+00	3.68E+00	3.44E+00	3.29E+00	9.44E-01	8.70E-01	1.07E+00	9.42E-01	8.26E-01	7.96E-01	6.86E-01	9.25E-01	7.58E-01	6.73E-01
Land use (100% occupied)	Raw	m2a	9.77E-01	9.12E-01	1.33E-01	8.50E-02	1.17E+00	9.77E-01	9.12E-01	1.33E-01	8.50E-02	1.20E+00	1.02E+00	9.12E-01	1.73E-01	8.50E-02	1.21E+00
Occupation, forest	Raw	m2a	1.23E-01	8.01E-02	5.93E-02	2.75E-02	1.36E-01	1.23E-01	8.01E-02	5.93E-02	2.75E-02	1.38E-01	1.25E-01	8.01E-02	6.15E-02	2.75E-02	1.39E-01
Occupation, traffic area	Raw	m2a	1.74E-02	1.67E-02	1.87E-02	1.75E-02	1.78E-02	1.73E-02	1.66E-02	1.87E-02	1.74E-02	1.78E-02	1.75E-02	1.67E-02	1.88E-02	1.75E-02	1.79E-02
Occupation, urban, continuously built	Raw	m2a	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Oil, crude, 42.0 MJ per kg, in ground	Raw	kg	1.02E-01	1.34E-01	1.41E-01	1.55E-01	8.92E-02	1.02E-01	1.33E-01	1.40E-01	1.54E-01	8.86E-02	1.03E-01	1.34E-01	1.42E-01	1.55E-01	8.98E-02
Oil, crude, 42.8 MJ per kg, in ground	Raw	kg	1.79E-01	1.74E-01	1.89E-01	1.80E-01	1.65E-01	5.07E-02	5.08E-02	6.09E-02	5.68E-02	4.37E-02	4.35E-02	4.19E-02	5.37E-02	4.78E-02	3.62E-02
Oil, crude, 43.4 MJ per kg, in ground	Raw	kg	4.65E-02	5.89E-02	6.15E-02	6.72E-02	4.11E-02	4.63E-02	5.86E-02	6.14E-02	6.68E-02	4.09E-02	4.70E-02	5.90E-02	6.21E-02	6.73E-02	4.14E-02
Water, fresh	Raw	m3	-3.16E-01	-1.35E-01	-8.75E-02	-8.75E-02	-3.28E-01	-3.16E-01	-1.35E-01	-8.75E-02	-8.75E-02	-3.27E-01	-3.13E-01	-1.35E-01	-8.51E-02	-8.75E-02	-3.26E-01
Water, unspecified natural origin/m3	Raw	m3	7.27E-01	5.00E-01	2.36E-01	2.35E-01	8.13E-01	7.27E-01	5.00E-01	2.36E-01	2.35E-01	8.18E-01	7.34E-01	5.00E-01	2.43E-01	2.35E-01	8.20E-01
Carbon dioxide, biogenic	Soil	kg	5.86E-01	4.33E-01	5.45E-02	5.45E-02	6.55E-01	5.86E-01	4.33E-01	5.45E-02	5.45E-02	6.65E-01	6.00E-01	4.33E-01	6.90E-02	5.45E-02	6.70E-01
ash	Waste	kg	3.65E-02	4.35E-02	3.81E-02	4.47E-02	3.62E-02	3.34E-02	3.85E-02	3.51E-02	3.96E-02	3.05E-02	3.89E-02	4.46E-02	4.06E-02	4.58E-02	3.61E-02
Mineral waste	Waste	kg	-3.76E-01	-4.26E-01	-3.63E-01	-4.18E-01	-1.41E-01	-3.76E-01	-4.26E-01	-3.62E-01	-4.18E-01	-1.41E-01	-3.76E-01	-4.26E-01	-3.63E-01	-4.18E-01	-1.41E-01
Waste, final, inert	Waste	kg	3.22E+00	4.17E+00	3.52E+00	4.30E+00	2.01E+00	3.23E+00	4.17E+00	3.53E+00	4.31E+00	2.03E+00	3.24E+00	4.17E+00	3.54E+00	4.31E+00	2.03E+00
Waste, fly ash	Waste	kg	1.26E-01	1.42E-01	1.28E-01	1.43E-01	1.32E-01	1.09E-01	1.15E-01	1.11E-01	1.15E-01	1.01E-01	1.39E-01	1.48E-01	1.41E-01	1.49E-01	1.32E-01
Waste, unspecified	Waste	kg	1.94E-02	2.48E-02	8.92E-02	6.60E-02	2.01E-02	1.94E-02	2.48E-02	8.92E-02	6.60E-02	2.01E-02	1.95E-02	2.48E-02	8.93E-02	6.60E-02	2.01E-02

8 Life Cycle Impact Assessment

Elementary flows across the system boundary, derived from the inventory described above, are assessed using the impact assessment method described in Section 5.6. The results are shown in Table 19, per functional unit.

8.1 Characterisation

Table 19 Characterisation (impacts per m^2.a).

Melbourne	unit	a	b	c	d	e
Global Warming	kg CO2e	12.6	13.0	13.6	13.6	12.0
Photochemical oxidation	kg C2H4	0.005	0.004	0.006	0.005	0.005
Eutrophication	kg PO4--- eq	0.011	0.011	0.011	0.011	0.010
Land use	Ha a	2.14E-04	2.03E-04	1.23E-04	1.15E-04	2.35E-04
Water Use	KL H2O	0.417	0.374	0.154	0.155	0.494
Solid waste	kg	3.0	4.0	3.4	4.2	2.1
Resource depletion	MJ Surplus	14.791	14.693	15.728	15.220	13.971
Cumulative Energy Demand	MJ LHV	182.8	182.5	192.1	187.2	174.2
Sydney						
Global Warming	kg CO2e	6.2	6.6	7.3	7.2	5.6
Photochemical oxidation	kg C2H4	0.003	0.003	0.004	0.003	0.003
Eutrophication	kg PO4--- eq	0.004	0.004	0.004	0.004	0.004
Land use	Ha a	2.14E-04	2.03E-04	1.22E-04	1.14E-04	2.37E-04
Water Use	KL H2O	0.416	0.373	0.153	0.154	0.499
Solid waste	kg	3.0	3.9	3.4	4.1	2.1
Resource depletion	MJ Surplus	5.897	5.951	6.834	6.478	5.292
Cumulative Energy Demand	MJ LHV	79.3	80.0	88.7	84.8	72.2
Brisbane						
Global Warming	kg CO2e	6.7	7.1	7.8	7.7	6.1
Photochemical oxidation	kg C2H4	0.003	0.003	0.004	0.003	0.003
Eutrophication	kg PO4--- eq	0.004	0.004	0.004	0.004	0.004
Land use	Ha a	2.18E-04	2.03E-04	1.27E-04	1.15E-04	2.39E-04
Water Use	KL H2O	0.427	0.374	0.164	0.156	0.504
Solid waste	kg	3.1	4.0	3.5	4.2	2.1
Resource depletion	MJ Surplus	5.927	5.915	6.867	6.443	5.314
Cumulative Energy Demand	MJ LHV	81.9	82.1	91.4	86.8	74.7

8.2 Normalisation

In order to better understand the relative order of magnitude of impacts, the characterisation result can be normalised using a known reference point. In this case, comparison of indicators with different units of measure is achieved by dividing the characterisation results by the total environmental impact of an average Australian. A value of 1 is therefore equivalent to the annual environmental impact of an Australian for that indicator, with a figure of 0.01 being equivalent to 1%.

The normalised results should not be interpreted as describing which indicators are most important, but rather they should be viewed as describing environmental impacts relative to a known baseline impact (good bad or indifferent).

The normalised results for Melbourne are shown in Figure 11. The normalised results indicate that the buildings considered contribute most significantly to the average Australian's solid waste impacts. They also indicate a relatively even contribution across global warming, photochemical oxidation, eurtrophication, water use, resource depletion and cumulative energy demand. The contribution to the average Australian's land use is minimal relative to the other impacts assessed.

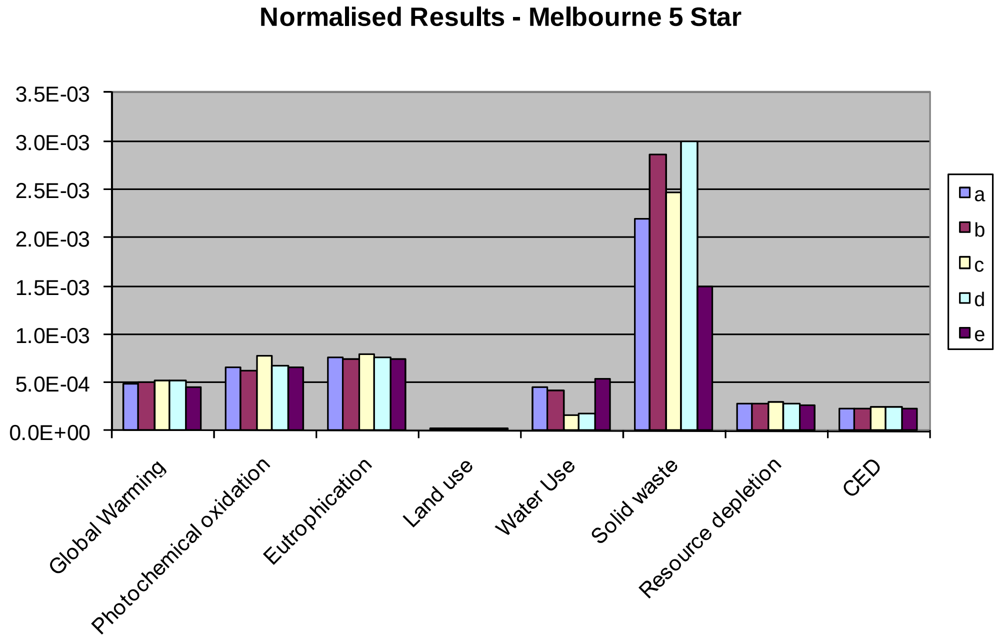


Figure 11 Normalised results - Melbourne 5 star.

Normalised results for the Sydney location are very similar to those of Melbourne (Figure 12).

Brisbane is not shown as it has very similar inter-indicator relativities as those shown for Sydney (refer Appendix F).

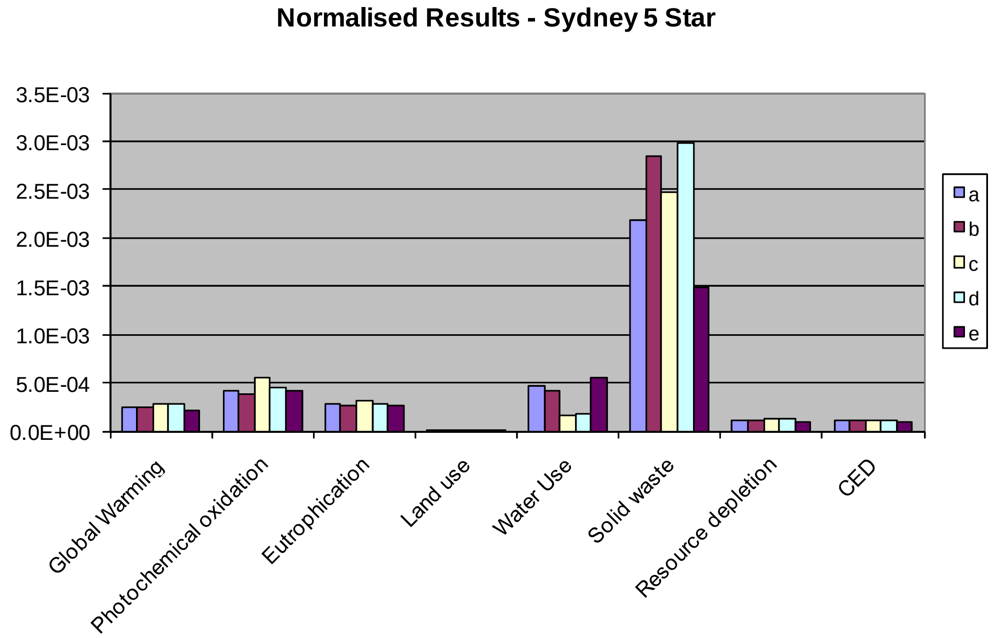


Figure 12 Normalised results - Sydney 5 star.

9 Discussion / Interpretation

9.1 Category impact indicators

As discussed in Section 5.6, the impact assessment methods chosen for the study have limitations when it comes to assessing actual environmental harm. Grant and Peters (2008) discuss these limitations in an Australian context and assess common category indicators as shown in Table 20.

Table 20 Impact category status and criteria for study inclusion (Grant and Peters 2008).

Indicator	Status	Relevance
Global warming	Ready to use	Always include in general assessment
Ozone depletion	Ready to use	Include if relevant emissions occur
Minerals and fossil fuels depletion (resource depletion)	Ready to use	Always include in general assessment
Human and ecotoxicity	Ready to use	Only when relevant emissions occur in system
Water use	Provisional method – needs development	Only when relevant consumption in system
Land use	Provisional method – needs development	Only when agriculture or forestry is significant in system
Eutrophication	Provisional method – needs refinement	When relevant non-energy emissions are prevalent
Photochemical oxidation	Ready to use	Only when relevant consumption in the system
Soil salinisation	Ready to use	Only when irrigated agriculture used in the system

A particular challenge of building related LCAs is the need to assess and contrast the potential environmental impacts of plant derived product systems, like timber, with mineral derived or synthesised materials like metals and plastics, because these systems tend to have directionally different outcomes depending on which indicator is being assessed. In this study the characterised results shown in Table 19 pose such a problem, with certain construction types generating relatively high impacts in certain indicators, and relatively low impacts in others. Compounding the problem is that certain indicators are considered ‘provisional’ and others are considered ‘ready to use’ (refer Table 20).

In this study water use and land use indicators present an interpretation challenge as both are considered ‘provisional’ and both present broadly contrary results to those of the ‘ready to use’ indicators.

9.1.1 Water use

The water indicator employed in this LCA does not make reference to scarcity nor the impact on the environment from which the water is extracted; it is simply a summation of all water used in the unit processes considered within the system boundary. This makes interpreting local environmental impacts associated with the indicator problematic, especially for the water consumed by forests, which in the timber LCI used in this study is based on the difference in water consumption between the forest and an alternative use (refer Section 7.3.1). For softwood timber, the water consumption is based on the difference in water use between a plantation forest and pasture. For hardwood timber, the water consumption is based on the difference in water use between a native forest available for wood production and one reserved for conservation.

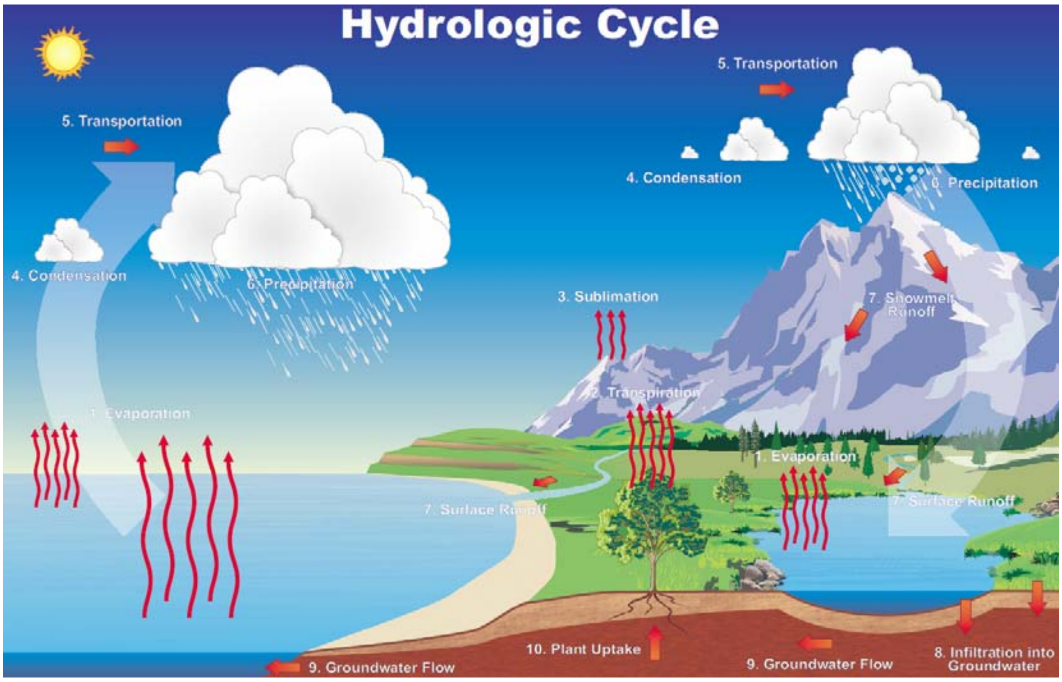


Figure 13 Hydrologic cycle (National Oceanic and Atmospheric Administration 2007).

Figure 13 illustrates the hydrologic cycle which incorporates the transpiration of water by trees and plants. As part of this cycle plantation and native forests tend to intercept more water from rainfall than do pastures and other crops (Parsons, Frakes et al. 2007).

Studies have been undertaken that show that forest plantations do indeed reduce run-off of water when compared to grasslands (Parsons, Frakes et al. 2007), however equating the impact of this diversion to environmental impacts is not straightforward. An alternative measure is required, beyond aggregate litres of water used, is required that allows information users to properly contextualise water used in the forestry process.

Water related impacts in LCA have been recognised as an area in need of development and work is being undertaken locally and internationally to improve assessment methods. One such study by Pfisister, Koehler et al. (2009) proposes an impact assessment method for water that addresses the issues described below:

> **Consumptive water use:** freshwater withdrawals which are evaporated, incorporated in products and waste, transferred into different watersheds, or disposed into the sea after use
> **Degradative use:** quality change in water used and released back to the same watershed
> **Regionalisation:** The ecological impacts of water use depend on many spatial factors, such as freshwater availability and use patterns at the specific location under study.
> **Damage to Human Health:** Two major water-scarcity related impact pathways for human health are generally observed: lack of freshwater for hygiene and ingestion, resulting in the spread of communicable diseases, and water shortages for irrigation, resulting in malnutrition.
> **Damage to Ecosystem Quality:** In places where plant growth is water-limited, withdrawals of blue water may eventually reduce the availability of green water and thus diminish vegetation and plant diversity
> **Damage to Resources:** In many locations, precipitation has an annual cycle, so this is the minimum time-step for evaluating whether water resource depletion has occurred.
>
> Source: (Pfister, Koehler et al. 2009)

In this study, the water indicator does not allow the reader to accurately quantify the impacts of the water used by the systems under study, but is arguably still a reasonable indicator of directional impact when differences are large. Despite its weaknesses, the water measure used does provide useful guidance as to which materials will be more likely to cause environmental stress if not managed appropriately. Provided care is taken to not equate water impacts with household potable water consumption (or other similar comparisons), the indicator can still provide useful guidance in a comparative study where differences are large.

9.1.2 Land use

Like water use, the land use indicator used in this study is imperfect and needs to be interpreted carefully. Land use in this study is a simple aggregate of all land occupied by the processes considered within the system boundary. How this then translates to environmental impact is not explicit, however is typically assumed to equate to the consumption of a resource (land) and an effect on an ecosystem outcome, such as a reduction in biodiversity. Unfortunately, drawing direct connections between land use and environmental impact is difficult, because the indicator used makes no attempt to address scarcity (neither as a resource measure nor as a biodiversity measure).

By occupying land, forests annex a precious resource (land) that as a consequence cannot be used for alternative purposes including those of the natural environment. Although it can be argued that they provide other benefits, it is clear that the use of the land resource needs to be allocated to the timber product generated from it. Assessing a biodiversity outcome, however, is more difficult, because the indicator used does not discern land conversion. A strong argument could be made that increased land use harms biodiversity if it is clear that native forest is being cleared to make way for plantation forest, however in this study this is not clear. It may be that forest has been planted upon marginal cropland, in which case biodiversity impacts would be quite different to those of native forest conversion. Given the scope of this study, drawing a conclusion on biodiversity is difficult without undertaking significant additional research.

Notwithstanding the above weaknesses, land use still provides guidance as to the likelihood of environmental impacts. Although the exact nature of land related impacts may be unclear, large differences in the indicator still allow directional conclusions to be drawn from a basic resource consumption perspective.

9.2 Life cycle stages

The characterised results shown in Table 19 describe a range of life cycle outcomes across the different constructions and regions. Before discussing results in detail, it is worthwhile comparing (where possible) the results shown to the existing literature assessed in Section 4, using the global warming indicator as a benchmark. The results achieved of between 5.6-13.6 kg CO2e per m2.a achieve a reasonable correlation with existing studies, which range between 13-47 kg CO2e per m2.a. (refer Figure 2). It is also worth noting that results are particularly comparable with the Maddox (2003) study, where construction and climate zones are similar (Maddox did not address elevated floors, however).

Within the characterised results, ranges of difference between construction types within a given climate are seen to be less pronounced than differences between the climates. This is due to the large influence of operational impact variation between the climate zones due to differences in the 5 star performance requirements, particularly between Melbourne and the Sydney-Brisbane zones (5-star homes must achieve heating/cooling loads of less than: 149MJ/m2a, 50MJ/m2a and 55MJ/m2a for Melbourne, Sydney and Brisbane, respectively[3]).

Figure 14 illustrates the differences in global warming impacts between climates for construction type (d) – negative values are associated with impact 'credits', usually driven by recycling of materials or the storage of carbon in timber in landfill (refer Section 7.7). Overall, building operation and maintenance contributes 56% to 77% of lifecycle global warming impacts for construction type (d), and that construction and materials contributes 23% to 44%. This result is significantly different to the results of Maddox and Nunn (2003) who stated that construction and materials impacts contribute 3-5% of lifecycle global warming potential[4].

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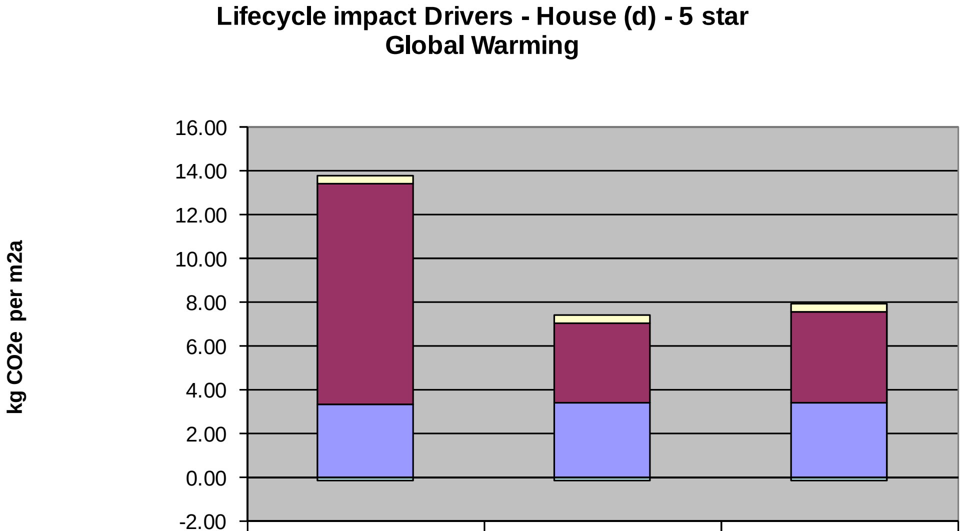
[3] Per unit of conditioned area.

[4] The main reason for this being a difference in system boundary whereby Maddox and Nunn included lighting, household appliances and hot water systems in addition to heating and cooling loads, however these devices have been excluded from this study as they are considered unrelated to construction type. Other differences also exist such as no use of insulation in the Maddox and Nunn building assessed, and a longer building life (60 years).

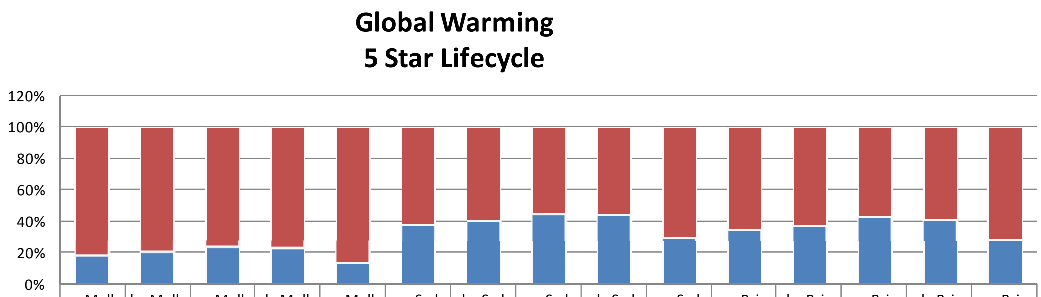


	Melbourne	Sydney	Brisbane
End of life	-0.15	-0.15	-0.15
Maintenance	0.37	0.37	0.37
Operation	10.05	3.65	4.16
Materials & constr.	3.33	3.35	3.34

End of life · Maintenance · Operation · Materials & constr.

Figure 14 Life cycle impact drivers per m2.a - House (d) - 5 star.

Figure 15 further illustrates the ratio of operation and maintenance global warming impacts to those of construction and materials for all the construction types assessed. The contribution of construction/materials[5] varies from 14% for construction type e in Melbourne to 45% for construction type c in Sydney. The significance of the result is that construction and materials play a major, and potentially increasing (as 6 star energy performance becomes mandatory) role in determining the lifecycle impacts of the buildings considered. The implications of further tightening in energy requirements (moving from 5 to 6 star performance requirements) is explored in a sensitivity study in Section 10.1.



	a - Melb	b - Melb	c - Melb	d - Melb	e - Melb	a - Syd	b - Syd	c - Syd	d - Syd	e - Syd	a - Bris	b - Bris	c - Bris	d - Bris	e - Bris
Operation	81%	80%	76%	77%	86%	62%	60%	55%	56%	70%	65%	62%	57%	59%	72%
Construction/Materials	19%	20%	24%	23%	14%	38%	40%	45%	44%	30%	35%	38%	43%	41%	28%

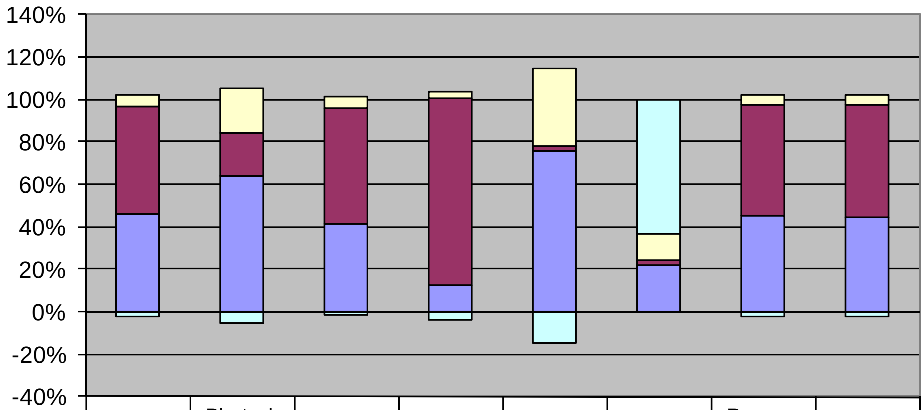
Figure 15 Construction and materials versus operation and maintenance in a 5 star construction types at various locations.

[5] Includes end-of-life impacts.

Other indicators (refer Figure 16), beyond global warming, comprise a range of operational versus material and construction ratios. Operation and maintenance effects contribute greater than 50% to eutrophication, land use, resource depletion and cumulative energy demand indicators. Material and construction impacts contribute greater than 50% to photochemical oxidation effects and water use indicators. Solid waste is driven more by the end-of-life phase. Both direct water consumption and household waste generation within the house during operation have been excluded from the study, hence impacts must be driven by construction, maintenance and end-of-life phases. Life cycle impact drivers for all the Melbourne climate houses are shown in Appendix G.

Overall, the results demonstrate that operational impacts are important drivers of life cycle impacts, however construction and material impacts are also significant in a five star performance environment.

Lifecycle impact Drivers - House (d) - Sydney - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-5%	-2%	-4%	-14%	63%	-3%	-2%
Maintenance	5%	21%	6%	3%	36%	13%	5%	5%
Operation	51%	20%	54%	88%	2%	2%	52%	53%
Materials & constr.	46%	64%	41%	12%	76%	22%	46%	44%

End of life Maintenance Operation Materials & constr.

Figure 16 Life cycle impact drivers per m^2.a - Construction type (d) - Sydney - 5 star

9.3 Construction types compared

The following tables compare the relative differences in impacts for the construction types (a) though to (e). The tables are created by calculating the fractional difference between construction types using the characterisation results shown in Table 19.

Comparisons have been drawn across three classifications. The first compares the difference between construction types utilising elevated floors and those using concrete slab floors (Table 21); the second compares timber framed houses to steel framed houses (Table 23); and the third compares weather board clad to brick veneer houses (Table 25).

In drawing the comparisons, the table cells have been shaded green where the item being compared has a lower impact and have been shaded yellow where it has a higher impact. In some cases rounding may make differences very difficult to discern.

9.3.1 Concrete slab versus elevated floor in a brick veneer construction.

Table 21 illustrates the performance of the elevated floor construction types relative to the concrete slab construction types. In general, the elevated floor construction types tend to have slightly lower global warming impacts (3-5% lower) when constructed from timber, however had slightly higher impacts when constructed from steel (0-1% higher). In general solid waste impacts across all elevated floor construction types were 20-30% lower. Other indicators tend to be higher for the elevated floor designs. .

Table 21 Elevated floor compared to concrete slab construction types.

	Melbourne		Sydney		Brisbane	
	(a-b)/a	(d-c)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c
Global Warming	-3%	0%	-5%	1%	-5%	1%
Photochemical oxidation	6%	13%	8%	18%	9%	19%
Eutrophication	2%	5%	2%	8%	4%	10%
Land use	5%	7%	5%	7%	7%	10%
Water Use	10%	-1%	11%	-1%	12%	5%
Solid waste	-30%	-21%	-30%	-21%	-29%	-20%
Resource depletion	1%	3%	-1%	5%	0%	6%
Cumulative Energy Demand	0%	3%	-1%	4%	0%	5%

Differences in outcomes stem from the impacts associated with the floor subsystems. Table 22 describes the life cycle impacts associated with one square metre of floor subsystem for the four construction types considered. The table shows the increased carbon intensity and solid waste associated with the manufacture of materials for the slab design. It also shows the water use associated with the timber elevated floor design.

Table 22 Life cycle impacts (excluding operation and maintenance) of 1m2 of floor for various floor sub-assemblies.

Impact category	Unit	Elevated timber floor (brick veneer application)	Elevated steel floor (brick veneer application)	Elevated timber floor (weatherboard application)	Concrete slab (brick veneer application)
Global Warming	kg CO2	30.5	58.6	15.0	48.5
Photochemical oxidation	kg C2H4	0.024	0.054	0.023	0.008
Eutrophication	kg PO4--- eq	0.018	0.035	0.013	0.018
Land use	Ha a	7.02E-04	5.20E-04	1.09E-03	4.14E-06
Water Use	KL H2O	3.6	0.8	4.4	0.8
Solid waste	kg	53.6	66.4	22.9	111.6
Resource depletion	MJ Surplus	28.812	54.971	14.651	35.000
Cumulative Energy Demand	MJ LHV	398.8	695.2	230.2	449.6

Water use in the elevated timber floor design is driven by the hardwood bearers and joists (Figure 17). Water, in this instance, is associated with the forest as discussed in Section 9.1.1. Water use impacts, although still significant in absolute terms, are partially offset by recycling of timber products at the end of the building lifecycle (shown in green in Figure 17).

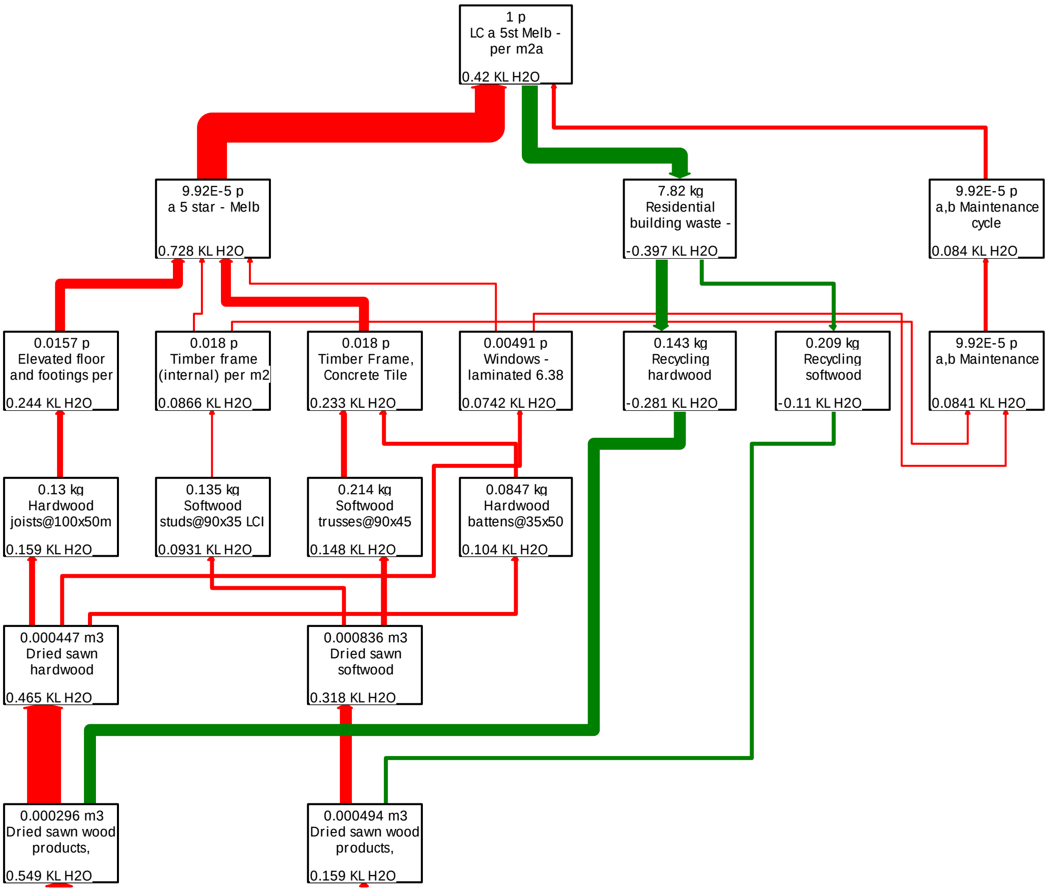


Figure 17 Water use in construction type (a). 5 star, Melbourne shown (10% cutoff)

9.3.2 Timber frame versus steel frame in a brick veneer construction.

The impact of timber framing versus steel framing is assessed by comparing construction types (a), (c), (b) and (d). This comparison effectively compares framing material in both an elevated floor and concrete slab design.

Table 23 describes the differences in the materials. In general, timber framing tends to have lower impacts across most indicators however tends to have higher impacts in water and land use.

Table 23 Timber frame compared to steel frame

	Melbourne		Sydney		Brisbane	
	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b
Global Warming	-9%	-5%	-17%	-5%	-9%	-5%
Photochemical oxidation	-19%	-10%	-30%	-10%	-19%	-10%
Eutrophication	-5%	-2%	-13%	-2%	-5%	-2%
Land use	43%	44%	43%	44%	43%	44%
Water Use	63%	58%	63%	58%	63%	58%
Solid waste	-13%	-5%	-13%	-5%	-13%	-5%
Resource depletion	-6%	-4%	-16%	-4%	-6%	-4%
Cumulative Energy Demand	-5%	-3%	-12%	-3%	-5%	-3%

Water and land use impacts are driven by timber used within both the floor (Table 22) and wall (Table 24) assemblies of the construction types..

Table 24 Life cycle impacts (excluding operation and maintenance) of 1m2 of wall for various sub-assemblies.

Impact category	Unit	Brick - timber frame	Brick - steel frame
Global Warming	kg CO2	48.4	59.2
Photochemical oxidation	kg C2H4	0.025	0.033
Eutrophication	kg PO4--- eq	0.023	0.028
Land use	Ha a	1.42E-03	3.68E-05
Water Use	KL H2O	3.2	0.0
Solid waste	kg	52.5	56.6
Resource depletion	MJ Surplus	51.159	60.580
Cumulative Energy Demand	MJ LHV	656.6	748.8

Forest management processes required to grow the trees required for timber production drive both the water and land use impacts of the timber framed construction types. Figure 18 illustrates how timber drives the bulk of land use impacts associated with the timber framed construction type. Like water use, these impacts are partially offset by recycling of timber at the end of the building lifecycle (shown in green in Figure 18).

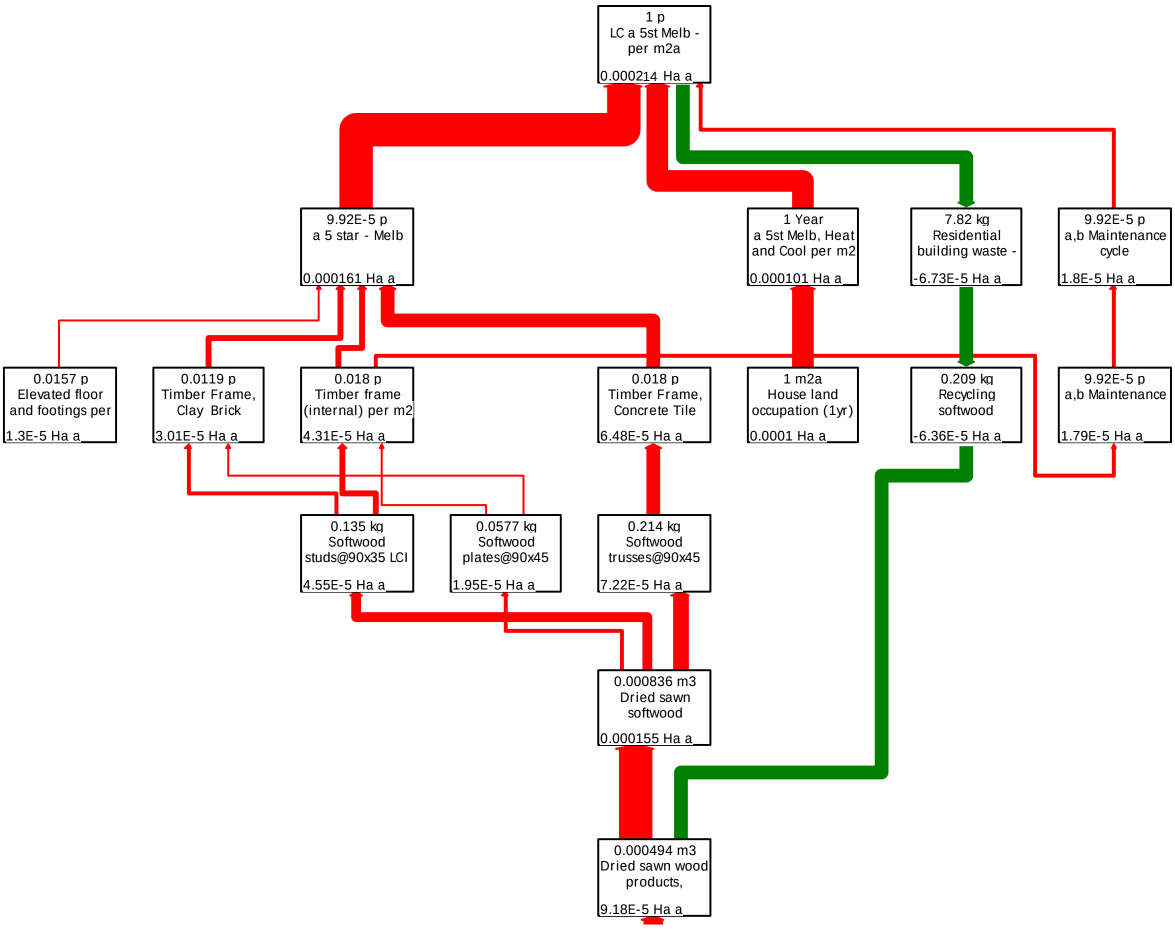


Figure 18 Land use in construction type (a). 5 star, Melbourne shown (6% cutoff).

9.3.3 Weatherboard versus brick

Weatherboard cladding versus a brick veneer construction types are assessed by comparing construction type (a) to construction type (e). Both constructions share a timber frame and elevated floor, with the single difference that type (a) uses a brick veneer wall assembly and type (e) uses weatherboards.

Table 25 describes the comparison, and shows that the weatherboard construction tends to have lower global warming, solid waste, resource depletion and embodied energy results, while brick tends to have lower photochemical oxidation, land use and water use impacts. The results are driven by the wall sub-assembly impacts which are shown in Table 26.

Table 25 Weatherboard compared to brick veneer

	Melbourne	Sydney	Brisbane
	(e-a)/e	(e-a)/e	(e-a)/e
Global Warming	-5%	-12%	-11%
Photochemical oxidation	-1%	1%	0%
Eutrophication	-4%	-4%	-4%
Land use	9%	10%	9%
Water Use	16%	17%	15%
Solid waste	-46%	-47%	-47%
Resource depletion	-6%	-11%	-12%
Cumulative Energy Demand	-5%	-10%	-10%

Table 26 Life cycle impacts (excluding maintenance) of 1m2 of wall for various sub-assemblies.

Impact category	Unit	Brick - timber frame	Weatherboard - timber frame
Global Warming	kg CO2	48.4	13.7
Photochemical oxidation	kg C2H4	0.025	0.018
Eutrophication	kg PO4--- eq	0.023	0.012
Land use	Ha a	1.42E-03	2.54E-03
Water Use	KL H2O	3.2	5.8
Solid waste	kg	52.5	6.5
Resource depletion	MJ Surplus	51.159	15.664
Cumulative Energy Demand	MJ LHV	656.6	246.7

Although the global warming difference shown in Table 26, is significant, this is diluted by other components of the building life cycle such as other carbon intensive materials in construction and the operation of the building over its life (Figure 19). In the example shown here, the brick walling system is 3.5 times more carbon intensive per square meter than the weatherboard clad wall structure, yet over the lifecycle of the building this difference reduces to a 5-12% greater global warming impact of the brick clad construction type versus the weatherboard.

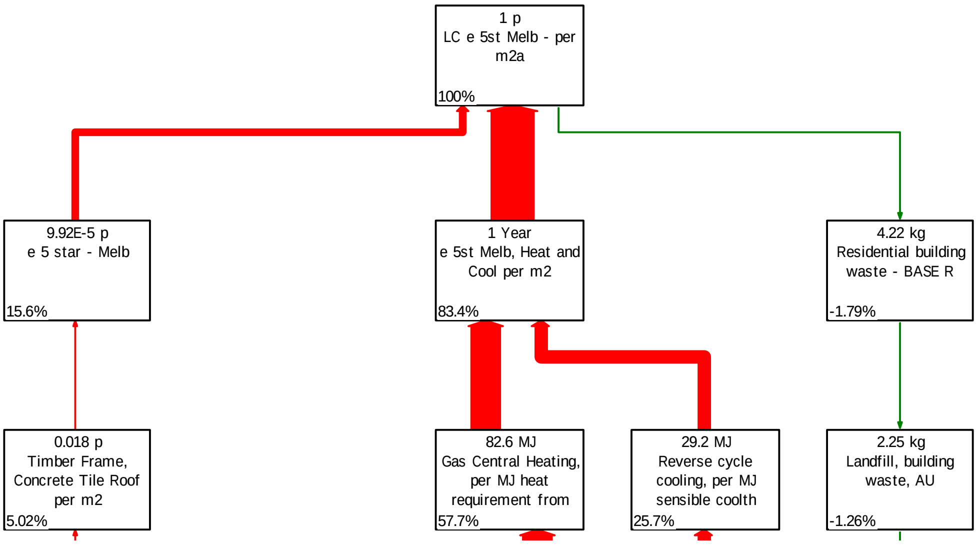
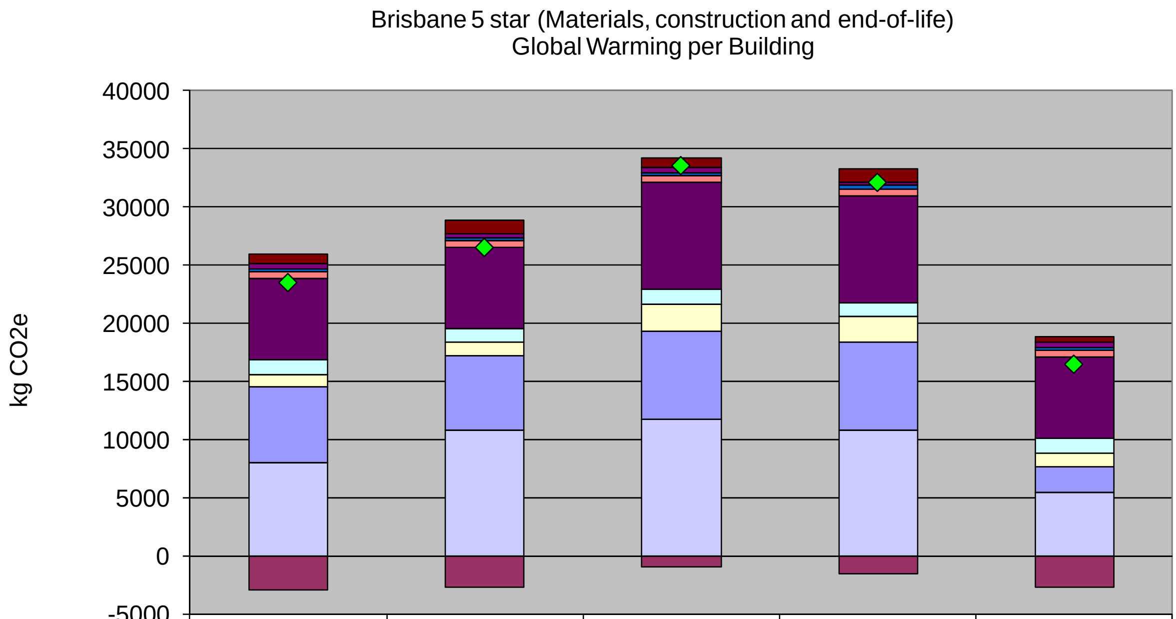


Figure 19 Global warming for construction type (e). 5 star, Melbourne shown (3% cutoff).

9.4 Impact drivers within each construction type – excluding operational impacts

The following section seeks to review the drivers of impacts within the construction types considered (excluding operational impacts). Rather than seeking to compare life cycle impacts as in Section 9.3, it looks at construction differences (including end-of-life) in isolation from operational and maintenance impacts, which tend to be similar for a given region.[6]

Differences between the life cycle impacts of the construction types are driven predominantly by differences in associated construction materials (both material manufacture and behaviour during the end of life phase). Figure 20 illustrates the drivers of Global Warming impacts caused by the major building subassemblies for each construction type in (Brisbane construction types shown as there is little difference between the climate zones). Global Warming impacts are predominantly driven by the Elevated floor, slab, external walls and roof sub assemblies. Houses incorporating the concrete slab floors (type b) and have 13% higher Global Warming impacts than the equivalent houses incorporating elevated floors in timber frame applications (type a), however have 4% lesser impacts than elevated floors in steel frame applications (type c compared to type d). Comparing framing types, differences are more pronounced with steel frame houses (type c and d) having 21-43% greater global warming impacts than equivalent timber framed houses (a and b). In terms of wall cladding, the brick veneer walled, elevated floor houses (type a) had 43% greater global warming impacts than the equivalent weatherboard house (type e).



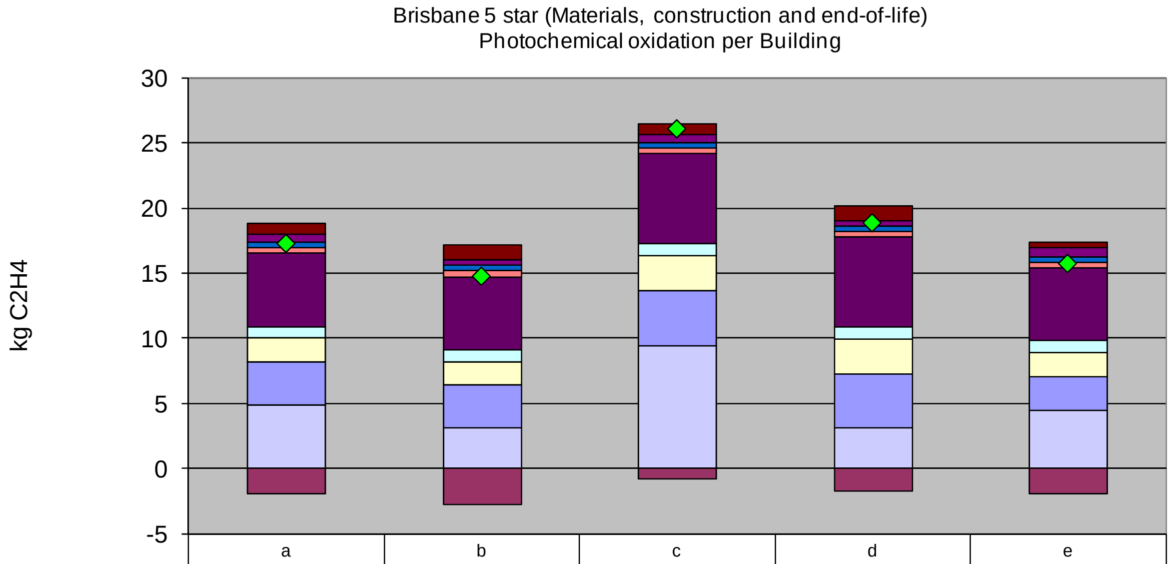
	a	b	c	d	e
Construction	853	1182	824	1163	455
Shading	412	304	412	304	412
Doors	286	286	286	286	286
Windows	535	555	587	555	535
Roof system	7025	7025	9201	9201	7025
Ceiling and ins.	1242	1174	1242	1174	1242
Internal wall system	1127	1127	2273	2273	1127
External wall system	6504	6463	7611	7573	2230
Floor system	8019	10788	11766	10788	5496
End of life	-2874	-2742	-971	-1537	-2669
Total	23494	26528	33596	32145	16441

Figure 20 Construction intensities per building (excludes operation and maintenance; includes construction and end-of-life), - Global Warming.

[6] Operational impacts are not identical within a given region and star rating due to slight variations in the fuel mix used to satisfy heating and cooling loads for each construction type.

Material and construction impacts for the, resource depletion and embodied energy indicators are similar to those seen for global warming and are presented in Appendix H.

Figure 21 illustrates the result for photochemical oxidation. In this instance photochemical oxidants tend to be higher for elevated floor construction types. In this case elevated floor construction types (a) and (c) generated 17-38% more photochemical oxidants than the concrete slab types (b) and (d). The brick veneer cladding construction type (a) generated 10% greater photochemical oxidants than the timber construction type (e).



	a	b	c	d	e
Construction	0.81	1.12	0.78	1.10	0.43
Shading	0.66	0.42	0.66	0.42	0.66
Doors	0.42	0.42	0.42	0.42	0.42
Windows	0.44	0.45	0.46	0.45	0.44
Roof system	5.61	5.61	6.92	6.92	5.61
Ceiling and ins.	0.90	0.89	0.90	0.89	0.90
Internal wall system	1.80	1.80	2.72	2.72	1.80
External wall system	3.31	3.30	4.15	4.14	2.57
Floor system	4.86	3.10	9.44	3.10	4.49
End of life	-1.97	-2.79	-0.82	-1.74	-1.95
Total	17.27	14.76	26.05	18.85	15.73

Figure 21 Construction intensities per building (excludes operation and maintenance; includes construction and end-of-life) - Photochemical Oxidation.

Photochemical oxidant emissions are caused by a range of processes as shown in Figure 22. Emissions are caused by timber drying processes and brick manufacturing processes predominantly. Emissions of methane from landfill (associated with timber) also cause photochemical oxidant related impacts.

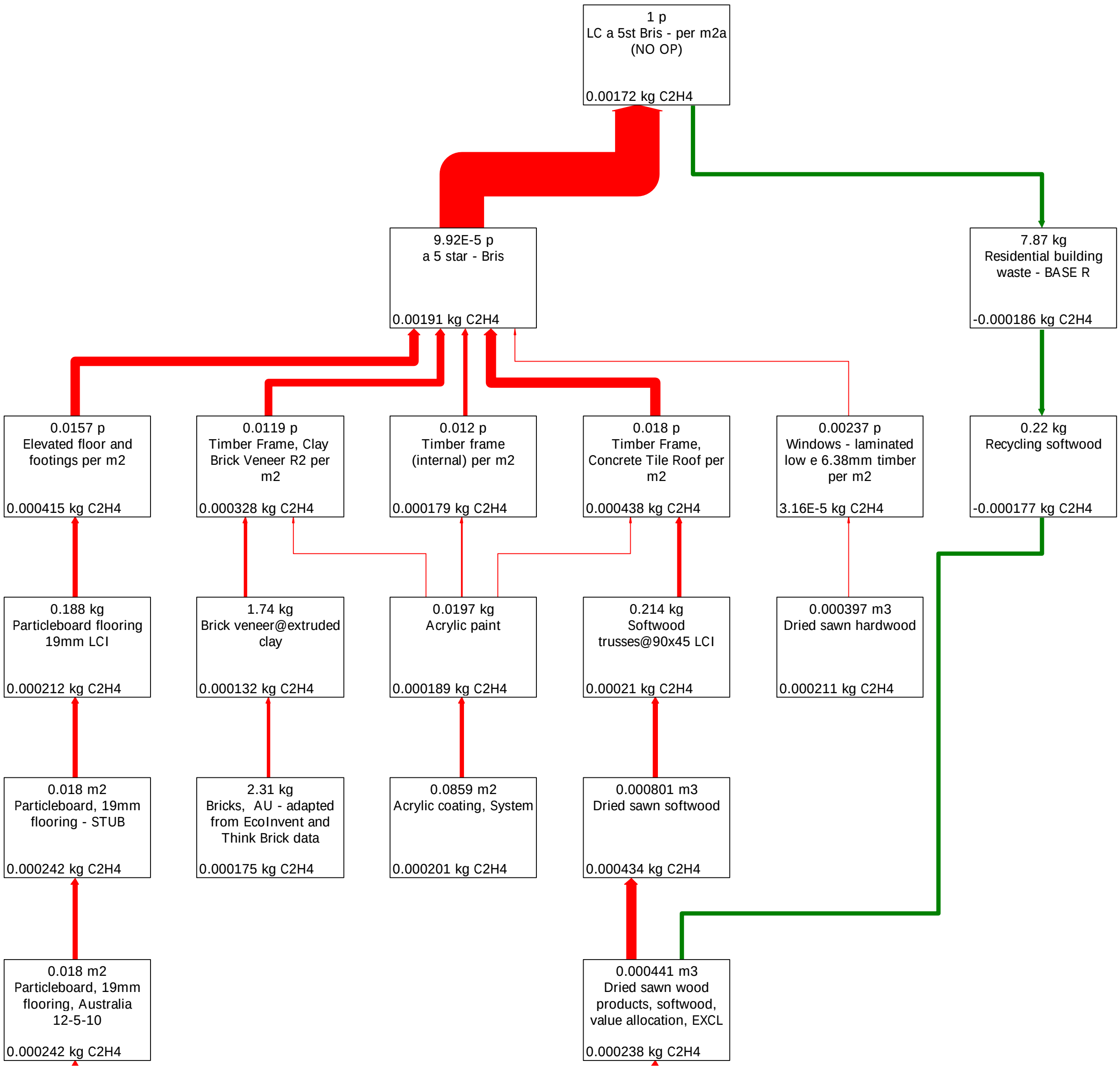
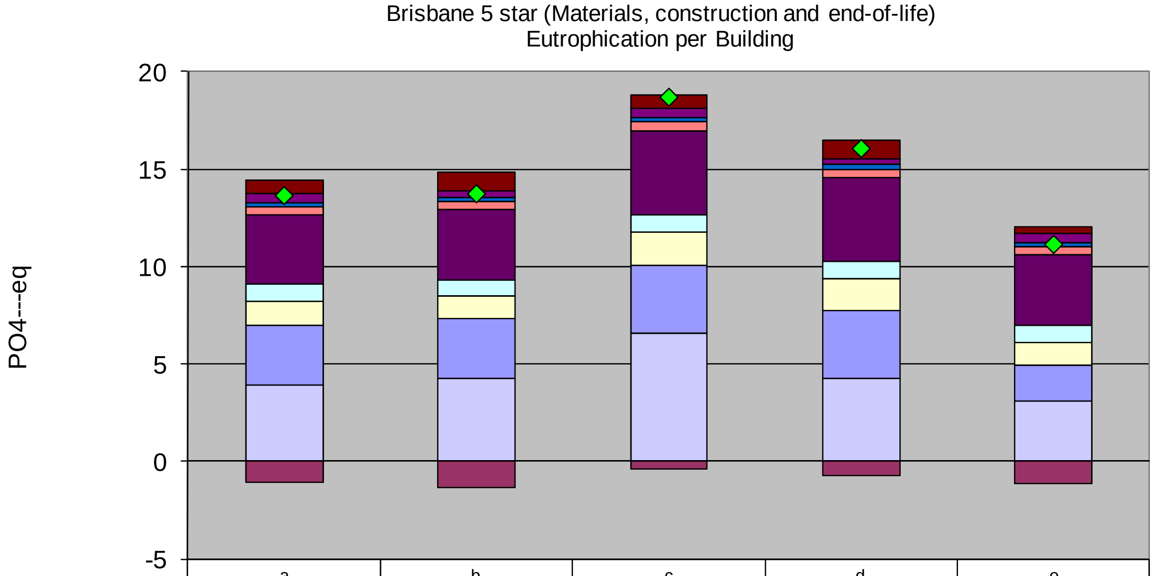


Figure 22 Photochemical oxidation drivers (excluding operation) - Construction type (a), Bris 5 star (9% cutoff). Results shown per m2.a.

Figure 23 illustrates eutrophication impacts associated with the construction types.



	a	b	c	d	e
Construction	0.71	0.98	0.69	0.97	0.38
Shading	0.47	0.32	0.47	0.32	0.47
Doors	0.22	0.22	0.22	0.22	0.22
Windows	0.40	0.41	0.43	0.41	0.40
Roof system	3.58	3.58	4.35	4.35	3.58
Ceiling and ins.	0.88	0.84	0.88	0.84	0.88
Internal wall system	1.18	1.18	1.65	1.65	1.18
External wall system	3.09	3.07	3.52	3.50	1.83
Floor system	3.93	4.24	6.57	4.24	3.11
End of life	-1.07	-1.37	-0.36	-0.72	-1.13
Total	13.63	13.72	18.66	16.04	11.13

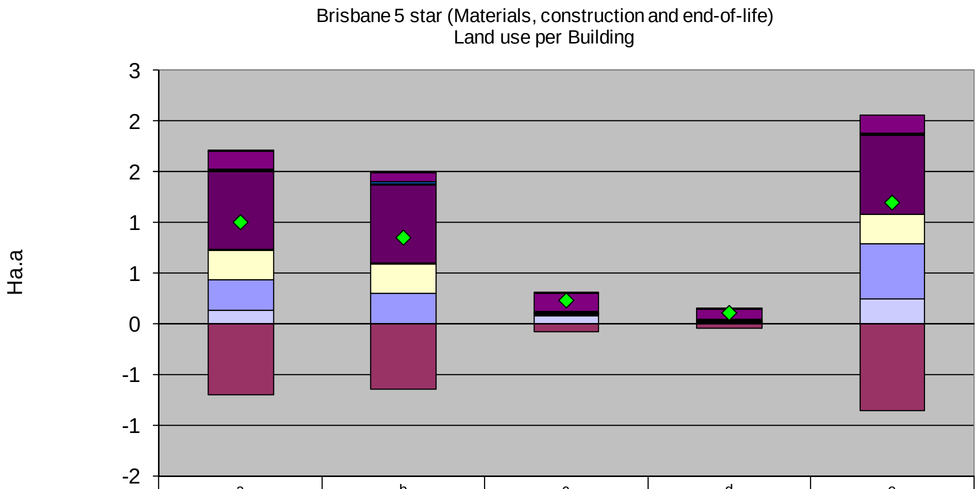
Figure 23 Construction intensities per building (excludes operation and maintenance; includes construction and end-of-life) - Eutrophication.

Table 27 describes the substances that cause eurtrophication impacts for Melbourne 5 star construction types. It shows that 89-96% of eutrophication impacts are caused by emissions to air and therefore may not necessarily cause environmental damage in an Australian context (Grant and Peters 2008). Eutrophication impacts associated with emissions to water are predominantly associated with phosphate based fertilisers used in forest management processes (associated with timber products), and are more likely to result in environmental impact, however the quantum of impact is far smaller that assessed for airborne emissions.

Table 27 Elementary flows causing eutrophication impacts for Brisbane, 5 star construction types (greater than 0.5% contribution shown).

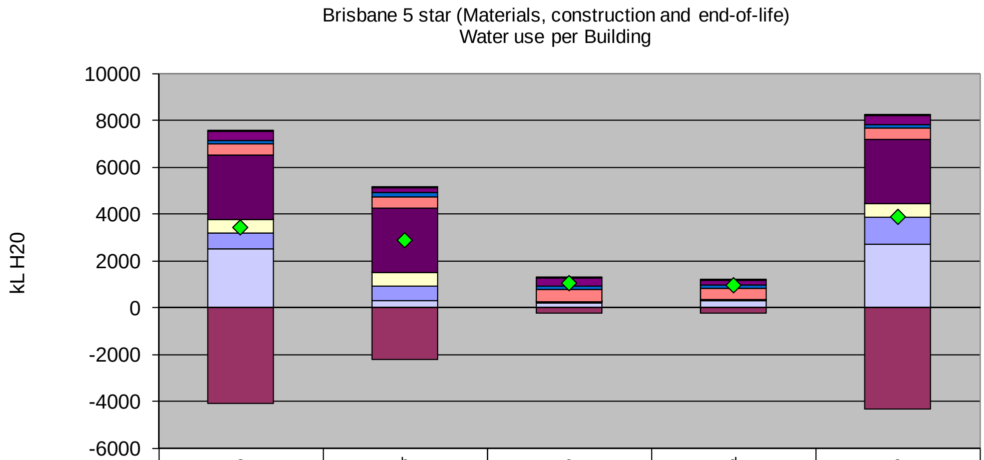
		Construction Type				
Substance	**Compartment**	**a**	**b**	**c**	**d**	**e**
Ammonia	Air	5%	4%	4%	3%	6%
Nitrogen oxides	Air	92%	93%	95%	96%	89%
Nitrate	Water	1%	1%	0%	0%	2%
Phosphate	Water	1%	1%	0%	0%	1%

Land Use and Water Use indicators follow different patterns to those seen for Global Warming. Sub-assemblies that drive impacts are elevated floor, external walls, and roof assemblies. Those construction types with the greatest impacts in these indicators are those using the greatest proportions of timber (type a,b and e), with timber houses having 4.5-8.5 times the land use impact and 3.0-3.7 times the water use impact of equivalent steel frame houses (refer Figure 24 and Figure 25). Reasons for such difference are related to the timber production process which incorporates agricultural processes which are discussed in detail in Section 9.3.



	a	b	c	d	e
Construction	0.00	0.00	0.00	0.00	0.00
Shading	0.17	0.10	0.17	0.10	0.17
Doors	0.01	0.01	0.01	0.01	0.01
Windows	0.01	0.01	0.01	0.01	0.01
Roof system	0.77	0.77	0.00	0.00	0.77
Ceiling and ins.	0.01	0.01	0.01	0.01	0.01
Internal wall system	0.29	0.29	0.01	0.01	0.29
External wall system	0.30	0.30	0.00	0.00	0.54
Floor system	0.13	0.00	0.08	0.00	0.24
End of life	-0.70	-0.65	-0.08	-0.04	-0.86
Total	1.00	0.85	0.22	0.10	1.20

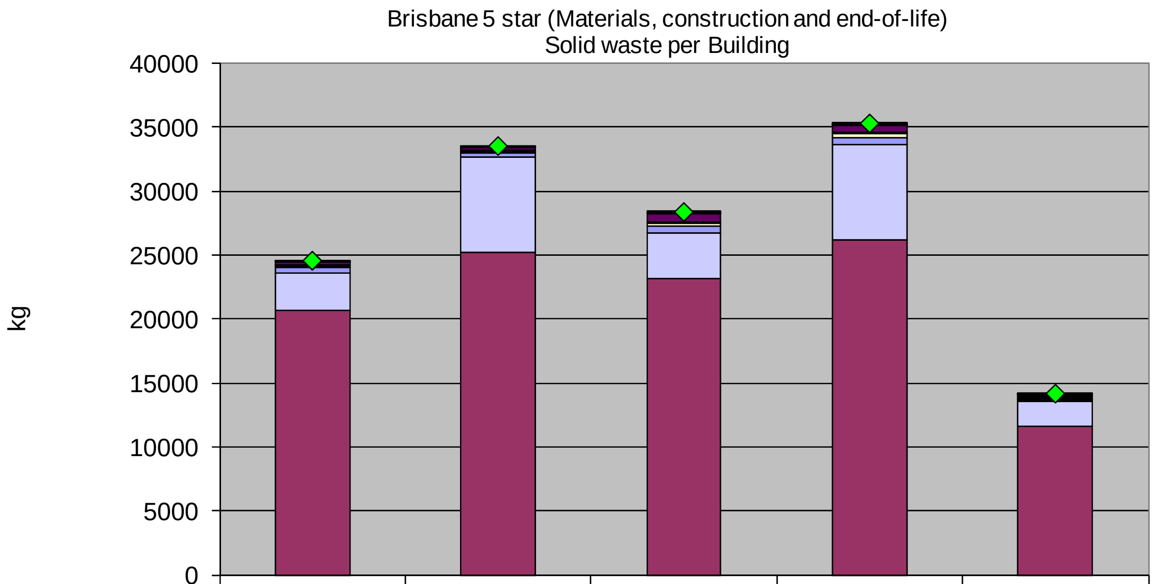
Figure 24 Construction intensities per building (excludes operation and maintenance; includes construction and end-of-life) - Land Use



	a	b	c	d	e
Construction	0	0	0	0	0
Shading	354	196	354	196	354
Doors	152	152	152	152	152
Windows	499	499	499	499	499
Roof system	2747	2747	27	27	2747
Ceiling and ins.	3	2	3	2	3
Internal wall system	582	582	4	4	582
External wall system	641	640	29	29	1121
Floor system	2521	271	204	271	2719
End of life	-4089	-2222	-224	-223	-4318
Total	3411	2869	1048	958	3860

Figure 25 Construction intensities per building (excludes operation and maintenance; includes construction and end-of-life) - Water Use

Solid waste impacts are caused by those construction types that incorporate higher mass materials and impacts and are mainly generated in the end-of-life lifecycle phase (refer Figure 26). Concrete slab construction types generate 24%-37% more solid waste than an equivalent elevated floor design. This result illustrates the dominance of the massive material types (concrete) over the solid waste outcome. The lightest weight construction type (e) has the lowest impact.



	a	b	c	d	e
Construction	0	0	0	0	0
Shading	49	31	49	31	49
Doors	7	7	7	7	7
Windows	15	16	17	16	15
Roof system	187	187	595	595	187
Ceiling and ins.	98	95	98	95	98
Internal wall system	102	102	276	276	102
External wall system	386	385	557	556	100
Floor system	2963	7444	3546	7444	1949
End of life	20723	25236	23199	26254	11629
Total	24568	33541	28383	35313	14167

Figure 26 Construction intensities per building (excludes operation and maintenance; includes construction and end-of-life) - Solid Waste.

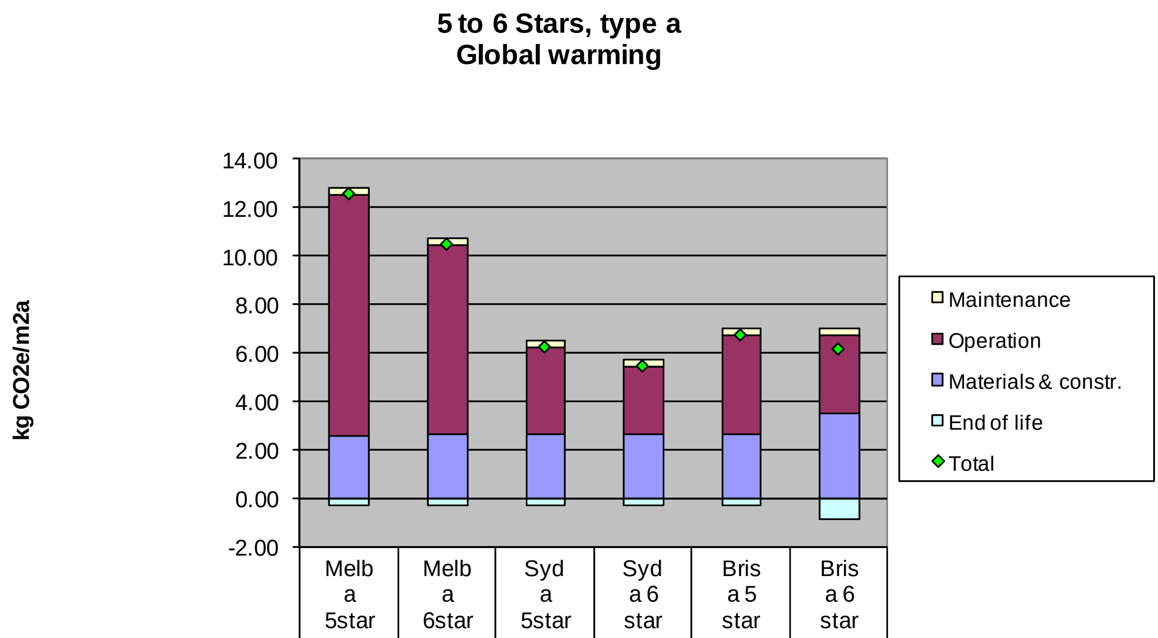
10 Validation

In order to check the sensitivity of study results to certain assumptions a number of sensitivity studies were undertaken as described in the following subsections. In addition to sensitivity analysis a non-assessed substance check was also undertaken (refer Appendix L).

10.1 5 star to 6 star

Increasing building efficiency from 5 star to 6 star performance across the regions considered has relevance in the current regulatory environment, where more stringent minimum performance regulations are being considered.

This sensitivity study tests the impact of 6 star building performance on the study conclusions arrived at above. In order to undertake the sensitivity, design interventions have been developed to improve efficiency from 5 to 6 stars for each construction type and climate zone, as shown in Appendix I. As in the base study, interventions are selected that do not affect the base design and that minimise incremental embodied energy.



	Melb a 5star	Melb a 6star	Syd a 5star	Syd a 6 star	Bris a 5 star	Bris a 6 star
Maintenance	0.30	0.30	0.30	0.30	0.30	0.30
Operation	9.95	7.83	3.62	2.84	4.11	3.24
Materials & constr.	2.59	2.63	2.60	2.60	2.62	3.47
End of life	-0.28	-0.28	-0.28	-0.29	-0.29	-0.86
Total	12.56	10.48	6.24	5.46	6.74	6.16

Figure 27 Global warming impacts when building performance is increased from 5 to 6 stars.

Figure 27 illustrates the reduction in global warming impacts associated with moving to 6 star performance for construction type (a). The result suggests a reduction in lifecycle impacts for construction type a of 9-17% after accounting for minimal increases in materials and construction impacts. Across all construction types and regions the reduction in global warming impact is 8-19%.

Figure 28 illustrates the ratio of operation and maintenance global warming impacts to those of construction and materials, for all the construction types assessed. The contribution of construction/materials[7] varies from 17% in for construction type e in Melbourne to 51% for construction type c in Sydney.

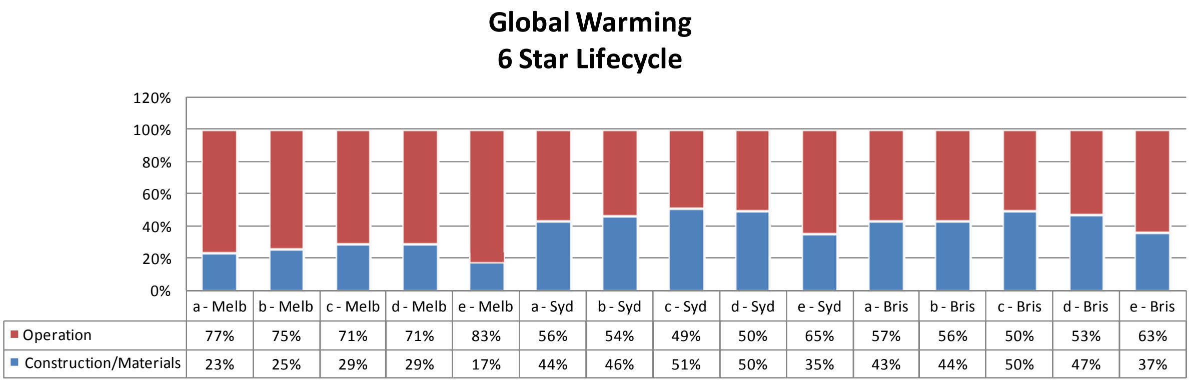


Figure 28 Construction and materials versus operation and maintenance in a 6 star construction types at various locations.

In addition to assessing the overall directional change, comparative results have also been assessed in a manner similar to that outlined in Section 9.3.

Table 28 illustrates those directional conclusions that change when moving from 5 to 6 star energy performance. The table shows that, in general, conclusions remain unchanged for global warming, solid waste and land use indicators, however some change occurs across resource depletion, water use and embodied energy. In most of these instances change tends to favour conclusions that show a lower impact for elevated floor designs.

The selective nature of change between concrete slab and elevated floors is due predominantly to changes in the mix of heating and cooling that occurs with the efficiency improvements selected. This is most apparent in the cooler climate zone (Melbourne) where heating as a percentage of total load drops from 75% to 71%, (refer Table 47) and operational loads represent a greater proportion of the lifecycle impact.

Table 28 Elevated floor compared to concrete slab 6 star (conclusion changes boxed in red)

	Melbourne		Sydney		Brisbane	
	(a-b)/a	(d-c)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c
Global Warming	-1%	3%	-5%	3%	-3%	4%
Photochemical oxidation	4%	12%	9%	19%	11%	20%
Eutrophication	-8%	-5%	-1%	6%	6%	12%
Land use	8%	7%	7%	10%	7%	9%
Water Use	14%	1%	13%	6%	6%	-15%
Solid waste	-27%	-19%	-29%	-20%	-29%	-20%
Resource depletion	-6%	-2%	-3%	4%	3%	9%
Cumulative Energy Demand	-3%	0%	-1%	5%	2%	7%

Conclusions with respect to framing and cladding remain unchanged when moving from 5 star to 6 star as shown by the minimal variation described in Table 29 and Table 30.

[7] Includes end-of-life impacts.

Table 29 Steel frame versus timber frame (steel/timber) 6 star

	Melbourne		Sydney		Brisbane	
	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b
Global Warming	-10%	-6%	-19%	-6%	-17%	-10%
Photochemical oxidation	-22%	-11%	-31%	-11%	-31%	-17%
Eutrophication	-6%	-3%	-15%	-3%	-16%	-8%
Land use	45%	45%	42%	45%	42%	44%
Water Use	66%	61%	62%	61%	67%	60%
Solid waste	-12%	-5%	-13%	-5%	-13%	-5%
Resource depletion	-8%	-4%	-18%	-4%	-18%	-10%
Cumulative Energy Demand	-6%	-3%	-13%	-3%	-13%	-7%

Table 30 Brick versus weatherboard (brick/weatherboard) 6 star

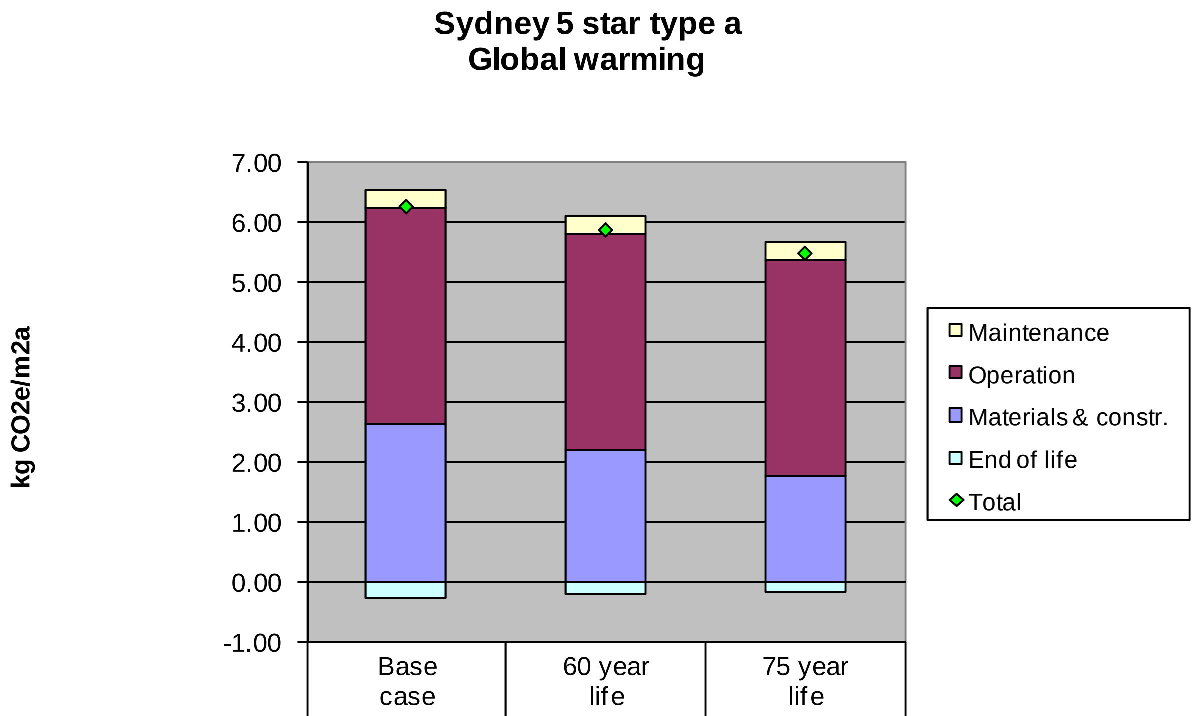
	Melbourne	Sydney	Brisbane
	(e-a)/e	(e-a)/e	(e-a)/e
Global Warming	-8%	-14%	-10%
Photochemical oxidation	2%	0%	1%
Eutrophication	2%	-6%	-6%
Land use	9%	9%	9%
Water Use	15%	15%	14%
Solid waste	-48%	-48%	-46%
Resource depletion	-3%	-14%	-13%
Cumulative Energy Demand	-4%	-12%	-10%

10.2 Lifetime

The lifetime of a construction type is difficult to forecast. Houses can last for extended periods if well maintained or they can be demolished prematurely because they become unfashionable. The house-life assumed in this study is 50 years, however this assumption is fundamentally arbitrary. In order to test conclusions under alternative house lifetimes, house-life has been extended from 50 to 60 and 75 years in this sensitivity study.

Figure 29 illustrates how changes in house-life affect global warming impacts for construction type (a). The figure illustrates how 'one-off' impacts such as materials, construction and end-of-life are reduced as lifetime is increased. Operational and maintenance impacts remain unchanged[8]. Materials, construction and end-of-life impacts reduce because they are divided over a longer building life.

[8] The figure illustrates the simplicity of the maintenance assumption which assumes linear impacts over the life of the house. Arguably maintenance would involve increased impacts as the house becomes older.



	Base case	60 year life	75 year life
Maintenance	0.30	0.30	0.30
Operation	3.62	3.62	3.62
Materials & constr.	2.60	2.17	1.74
End of life	-0.28	-0.23	-0.19
Total	6.24	5.85	5.47

Figure 29 Sensitivity of global warming impacts to changes in house-life (per m^2.a).

Apart from reducing the overall lifecycle impact across all indicators, building life does not change relative conclusions.

10.3 End of life of construction materials

Numerous possibilities exist for the treatment of building materials at the end of the building lifetime. The base assumption used in this study assumes a mix of recycling and landfill (refer Section 7.7) that would be expected to vary widely in reality. In addition, when materials are landfilled, certain assumptions have been made regarding the treatment of carbon within the landfill (as discussed in Section 7.7.1). Landfill assumptions predominantly affect timber product global warming impacts.

This sensitivity tests end-of-life assumptions by undertaking alternative end-of-life scenarios as summarised below:

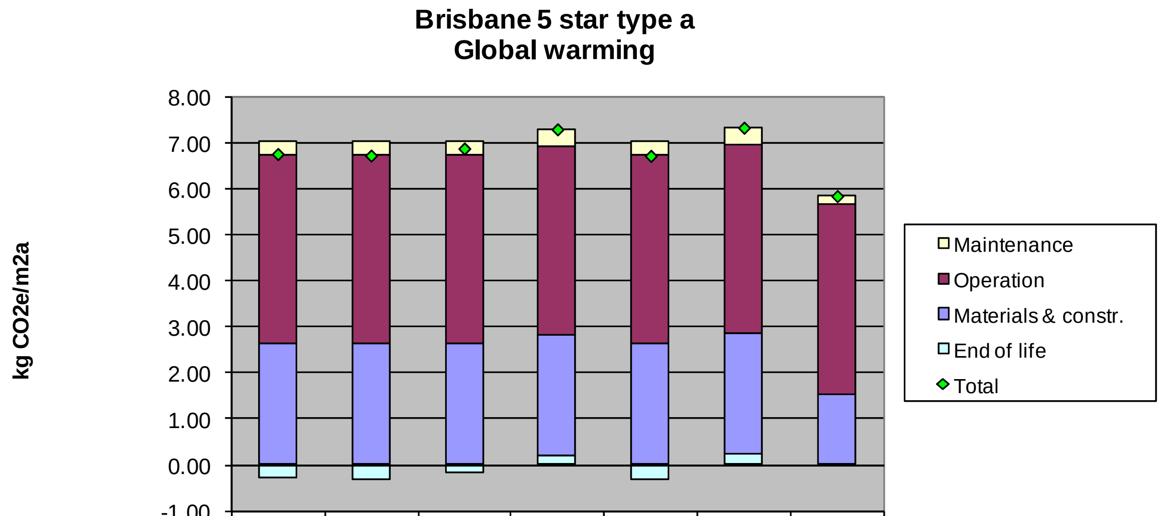
Table 31 End of life scenarios considered.

No.	End of life scenario	% Recycle	% Landfill	kg Methane generation/kg timber deposited	kg Carbon sequestration/kg timber deposited	kg Carbon/kg timber deposited	% methane capture	Carbon stored in house timber
0	Base case	Mix	Mix	90	310	500	36%	0%
1	100% Recycle - assumes 100% of building materials are recycled at the end of the building's life.	100%	0%	90	310	500	36%	0%
2	100% Landfill - assumes 100% of building materials are landfilled at the end of the building's life.	0%	100%	90	310	500	36%	0%
3	IPCC - Uses the IPCC guideance for treatment of timber in landfill	Mix	Mix	143	215	430	36%	0%
4	Ximenes - Modifies the US EPA (base case) method for determining emissions from landfill to increase carbon fraction sequestered. Based on Ximenes and Gardner et al.	Mix	Mix	90	415	500	36%	0%
5	No sequestration - Assumes no sequestration of carbon in landfill.	Mix	Mix	90	0	500	36%	0%
6	Sequester in house - Assumes house is not demolished and that carbon is permenantly stored in its structure.	Mix	Mix	NA	NA	NA	NA	100%

Altering the end-of-life assumptions, as described above, predominantly affects the solid waste and global warming indicators. Figure 30 illustrates the outcomes for the type (a) construction located in Brisbane. The results show little change in global warming impacts as recycling versus land fill assumptions are altered (scenarios 1 and 2). This is due to global warming reductions due to recycling being offset by reductions in sequestration in landfill for the type (a) construction assessed.

Landfill related assumptions (scenarios 3,4 and 5) have more significant effects. Altering assumptions in line with IPCC guidance (refer Section 7.7.1.1) reduces the quantity of carbon stored in landfill and increases methane emissions, resulting in an increase in global warming emissions. Ximenes and Gardner (2008) has an opposite effect, by increasing the carbon expected to be stored in landfill. Removal of the sequestration assumption entirely, significantly increases global warming impacts, as landfill of timber is no longer allocated a ‘carbon credit’ for carbon storage.

The final scenario, sequestration of carbon within the house structure during use, assumes that the house is maintained in the long term and that it represents an incremental additional carbon sink. This scenario has the most advantageous global warming outcome as 100% of carbon in timber is effectively stored.



	Base case	100% Landfill	100% Recycle	IPCC	Ximenes	No sequestration	Sequester in house
Maintenance	0.30	0.30	0.30	0.35	0.30	0.35	0.18
Operation	4.11	4.11	4.11	4.11	4.11	4.11	4.11
Materials & constr.	2.62	2.62	2.62	2.62	2.62	2.62	1.54
End of life	-0.29	-0.32	-0.17	0.19	-0.33	0.23	0.00
Total	6.74	6.70	6.85	7.27	6.70	7.30	5.83

Figure 30 Sensitivity of global warming impacts to changes in end of life assumptions (per m^2.a).

Table 32, Table 33 and Table 34 describe the impacts of sensitivity analysis on study comparative conclusions. Broadly, the scenarios considered have minimal impact on the comparison between the concrete floor and the elevated floor, with the concrete floor tending to have higher impacts (Table 32).

Table 32 Concrete slab floor versus elevated floor (slab/elevated) 5 star (Brisbane only)

	Base case		100% Landfill		100% Recycle		IPCC		Ximenes		No Sequestration		Sequester in house	
	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c
Global Warming	-5%	1%	-7%	0%	-4%	2%	-3%	1%	-5%	1%	-3%	1%	-11%	1%
Photochemical oxidation	9%	19%	7%	16%	9%	20%	9%	19%	9%	19%	9%	19%	9%	19%
Eutrophication	4%	10%	3%	8%	4%	10%	4%	10%	4%	10%	4%	10%	4%	10%
Land use	7%	10%	7%	12%	6%	7%	7%	10%	7%	10%	7%	10%	7%	10%
Water Use	12%	5%	29%	5%	-490%	4%	12%	5%	12%	5%	12%	5%	12%	5%
Solid waste	-29%	-20%	-51%	-49%	74%	61%	-29%	-20%	-29%	-20%	-29%	-20%	-29%	-20%
Resource depletion	0%	6%	-1%	5%	1%	7%	0%	6%	0%	6%	0%	6%	0%	6%
Cumulative energy demand	0%	5%	-1%	4%	0%	5%	0%	5%	0%	5%	0%	5%	0%	5%

The comparison between steel framing and timber framing is not affected significantly by end-of-life assumptions (Table 33).

Brick versus weatherboard conclusions remain unchanged (Table 34).

Table 33 Steel frame versus timber frame (steel/timber) 5 star (Brisbane only)

	Base case		100% Landfill		100% Recycle		IPCC		Ximenes		No Sequestration		Sequester in house	
	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b
Global Warming	-9%	-5%	-18%	-10%	-14%	-7%	-8%	-4%	-17%	-9%	-7%	-3%	-37%	-23%
Photochemical oxidation	-19%	-10%	-16%	-6%	-47%	-29%	-26%	-13%	-30%	-16%	-30%	-16%	-30%	-16%
Eutrophication	-5%	-2%	-10%	-4%	-18%	-10%	-14%	-7%	-14%	-7%	-14%	-7%	-14%	-7%
Land use	43%	44%	53%	56%	19%	20%	42%	44%	42%	44%	42%	44%	42%	44%
Water Use	63%	58%	78%	70%	-437%	12%	62%	58%	62%	58%	62%	58%	62%	58%
Solid waste	-13%	-5%	-2%	0%	-73%	-158%	-13%	-5%	-13%	-5%	-13%	-5%	-13%	-5%
Resource depletion	-6%	-4%	-15%	-8%	-16%	-9%	-16%	-9%	-16%	-9%	-16%	-9%	-16%	-9%
Cumulative energy demand	-5%	-3%	-9%	-4%	-14%	-8%	-11%	-6%	-12%	-6%	-12%	-6%	-12%	-6%

Table 34 Brick versus weatherboard (brick/weatherboard) 5 star (Brisbane only)

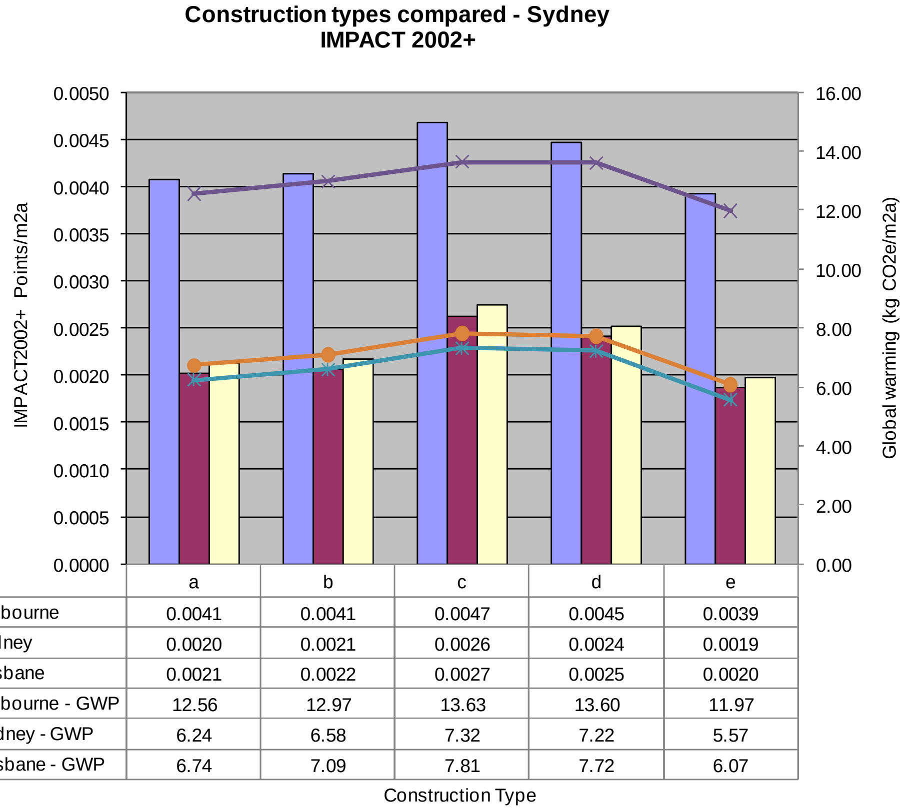
	Base case	100% Landfill	100% Recycle	IPCC	Ximenes	No Sequestration	Sequester in house
	(e-a)/e	(e-a)/e	(e-a)/e	(e-a)/e	(e-a)/e	(e-a)/e	(e-a)/e
Global Warming	-11%	-13%	-10%	-9%	-11%	-9%	-18%
Photochemical oxidation	0%	1%	-1%	1%	0%	0%	0%
Eutrophication	-4%	-4%	-5%	-4%	-4%	-4%	-4%
Land use	9%	11%	3%	9%	9%	9%	9%
Water Use	15%	11%	65%	15%	15%	15%	15%
Solid waste	-47%	-76%	-3%	-47%	-47%	-47%	-47%
Resource depletion	-12%	-12%	-11%	-12%	-12%	-12%	-12%
Cumulative energy demand	-10%	-10%	-10%	-10%	-10%	-10%	-10%

Overall, end of life assumptions appear to only directionally change conclusions under a '100% recycling' scenario for the photochemical oxidation, water use and land use indicators. In general, 100% recycling reduces solid waste impacts for higher mass construction types, such as type (c) and (d), making them preferable versus the elevated floor designs in this indicator. Water use impacts and photochemical oxidation impacts are reduced for timber intensive designs, making elevated floors preferable, timber walls preferable and timber cladding, in the water use indicator.

10.4 IMPACT 2002+

Assessment of results across 8 indicators can make interpretation difficult, especially when indicators such as global warming and water use suggest opposite conclusions. Integrated methods such as IMPACT 2002+ (Jolliet, Margni et al. 2003), resolve these issues by applying normalisation and weighting to the midpoint indicators to enable presentation of results as a single score.

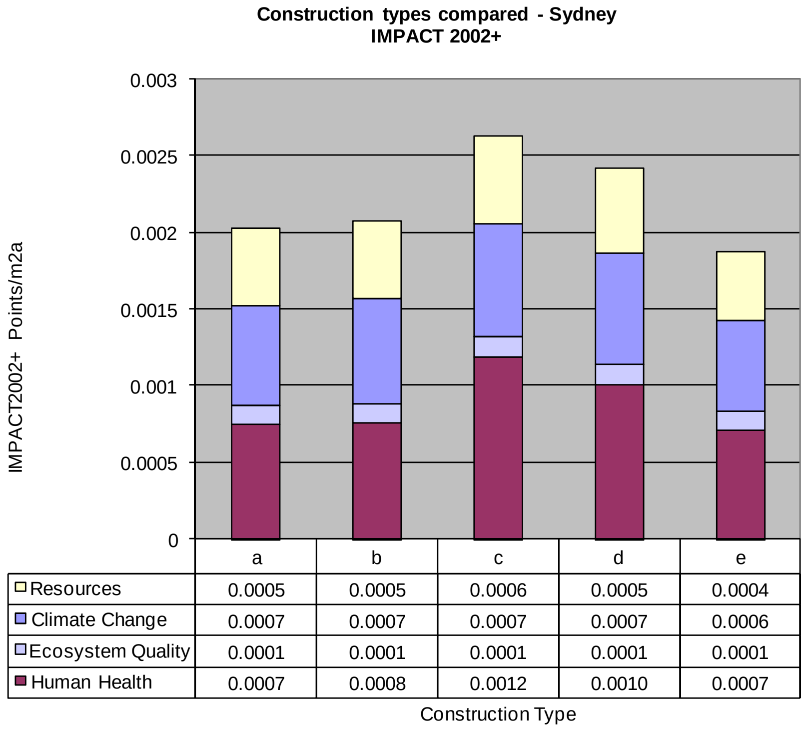
The characterisation for this study is shown recalculated using the impact assessment method IMPACT 2002+ in Figure 31, and resulting construction relativities in Table 35.



	a	b	c	d	e
Melbourne	0.0041	0.0041	0.0047	0.0045	0.0039
Sydney	0.0020	0.0021	0.0026	0.0024	0.0019
Brisbane	0.0021	0.0022	0.0027	0.0025	0.0020
Melbourne - GWP	12.56	12.97	13.63	13.60	11.97
Sydney - GWP	6.24	6.58	7.32	7.22	5.57
Brisbane - GWP	6.74	7.09	7.81	7.72	6.07

Figure 31 Characterisation using IMPACT 2002+ (per m2.a).

The results shown in Figure 31 are directionally consistent with the global warming results shown as lines on Figure 31 . This result is understandable given the core drivers of the IMPACT 2002+ score, shown for Sydney in Figure 32.



	a	b	c	d	e
Resources	0.0005	0.0005	0.0006	0.0005	0.0004
Climate Change	0.0007	0.0007	0.0007	0.0007	0.0006
Ecosystem Quality	0.0001	0.0001	0.0001	0.0001	0.0001
Human Health	0.0007	0.0008	0.0012	0.0010	0.0007

Figure 32 Breakdown of IMPACT 2002+ drivers for Sydney (per m^2.a).

Bearing in mind the drivers shown in Figure 32, the relative results shown in Table 35 are unsurprising. The method suggests that the timber floor, wall and roof structure and cladding have lower impacts than alternatives.

Table 35 Construction types compared (IMPACT 2002+).

	Melbourne		Sydney		Brisbane	
	(a-b)/a	(d-c)/c	(a-b)/a	(c-d)/c	(a-b)/a	(c-d)/c
Elevated floor compared to slab	-1%	-5%	-2%	8%	-2%	8%

	Melbourne		Sydney		Brisbane	
	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b	(a-c)/a	(b-d)/b
Timber frame compared to steel frame	-15%	-8%	-30%	-17%	-29%	-16%

	Melbourne	Sydney	Brisbane
	(e-a)/e	(e-a)/e	(e-a)/e
Weatherboard compared to brick veneer	-4%	0%	-8%

The IMPACT 2002+ method simplifies the assessment process considerably, however it does so at the expense of transparency. Understanding why a particular result is achieved can be difficult, however this shortcoming arguably applies to all end-point assessment methods.

10.5 Alternative treatment of recycled steel

In the base assessment, the recycling of steel is assumed to avoid steel production impacts as described in Section 7.7. In Section 7.7, recycled structural steel is assumed to avoid the production of reinforcing steel from the EAF process and that recycled reinforcing steel, already produced from recycled feedstock, does not avoid any impacts because the avoided impacts have already been assessed as part of the reinforcing steel production inventory.

An alternative to this approach would be to assess the avoided impacts associated with recycling all steel products on the basis of the global production BOF and EAF steel. According to the World Steel

Association (2009), 67.2% of steel was produced from the BOF process, 30.6% from the EAF process and 2.2% from Open Hearth process. Assuming that Open Hearth steel processes are more similar to BOF, recycled steel is assumed to avoid 31% EAF steel and 69% BOF steel.

Table 36 Characterisation of impacts for Brisbane locations under the base scenario and assuming an alternative treatment of recycled steel material.

		a		b		c		d		e	
Impact category	Unit	BASE	BOF/EAF	BASE	BOF/EAF	BASE	BOF/EAF	BASE	BOF/EAF	BASE	BOF/EAF
Global Warming	kg CO2	6.7	6.7	7.1	7.1	7.8	7.8	7.7	7.7	6.1	6.1
Photochemical oxidation	kg C2H4	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003
Eutrophication	kg PO4--- eq	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Land use	Ha a	2.18E-04	2.18E-04	2.03E-04	2.03E-04	1.27E-04	1.27E-04	1.15E-04	1.15E-04	2.39E-04	2.39E-04
Water Use	KL H2O	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.5	0.5
Solid waste	kg	3.1	3.1	4.0	4.0	3.5	3.5	4.2	4.2	2.1	2.1
Resource depletion	MJ Surplus	5.927	5.918	5.915	5.887	6.867	6.858	6.443	6.415	5.314	5.309
Cumulative Energy Demand	MJ LHV	81.9	81.8	82.1	81.8	91.4	91.3	86.8	86.5	74.7	74.7

Table 36 illustrates the revised impacts under the BOF/EAF substitution scenario. Results are affected most significantly for construction type c as it contains the most steel. Change is however quite small, with global warming impacts reducing by approximately 1%. Overall, the change of assumptions does not change study conclusions.

11 Conclusions

The characterisation of impacts, repeated in Table 37 below, describes the environmental profile for a square metre-year for each of the construction types considered. The characterisation achieved appears broadly consistent with existing LCA studies reviewed (for the global warming indicator).

Table 37 Characterisation (impacts per m^2.a) for each construction type.

Melbourne	unit	a	b	c	d	e
Global Warming	kg CO2e	12.6	13.0	13.6	13.6	12.0
Photochemical oxidation	kg C2H4	0.005	0.004	0.006	0.005	0.005
Eutrophication	kg PO4--- eq	0.011	0.011	0.011	0.011	0.010
Land use	Ha a	2.14E-04	2.03E-04	1.23E-04	1.15E-04	2.35E-04
Water Use	KL H2O	0.4	0.4	0.2	0.2	0.5
Solid waste	kg	3.0	4.0	3.4	4.2	2.1
Resource depletion	MJ Surplus	14.791	14.693	15.728	15.220	13.971
Cumulative Energy Demand	MJ LHV	182.8	182.5	192.1	187.2	174.2
Sydney						
Global Warming	kg CO2e	6.2	6.6	7.3	7.2	5.6
Photochemical oxidation	kg C2H4	0.003	0.003	0.004	0.003	0.003
Eutrophication	kg PO4--- eq	0.004	0.004	0.004	0.004	0.004
Land use	Ha a	2.14E-04	2.03E-04	1.22E-04	1.14E-04	2.37E-04
Water Use	KL H2O	0.416	0.373	0.153	0.154	0.499
Solid waste	kg	3.0	3.9	3.4	4.1	2.1
Resource depletion	MJ Surplus	5.897	5.951	6.834	6.478	5.292
Cumulative Energy Demand	MJ LHV	79.3	80.0	88.7	84.8	72.2
Brisbane						
Global Warming	kg CO2e	6.7	7.1	7.8	7.7	6.1
Photochemical oxidation	kg C2H4	0.003	0.003	0.004	0.003	0.003
Eutrophication	kg PO4--- eq	0.004	0.004	0.004	0.004	0.004
Land use	Ha a	2.18E-04	2.03E-04	1.27E-04	1.15E-04	2.39E-04
Water Use	KL H2O	0.427	0.374	0.164	0.156	0.504
Solid waste	kg	3.1	4.0	3.5	4.2	2.1
Resource depletion	MJ Surplus	5.927	5.915	6.867	6.443	5.314
Cumulative Energy Demand	MJ LHV	81.9	82.1	91.4	86.8	74.7

Normalising outcomes for Australian average impacts suggests that land use results represent a very small portion of per-capita impacts and that solid waste outcomes reflect large portions of per capita impacts (refer Figure 33). Other indicators are relatively evenly balanced.

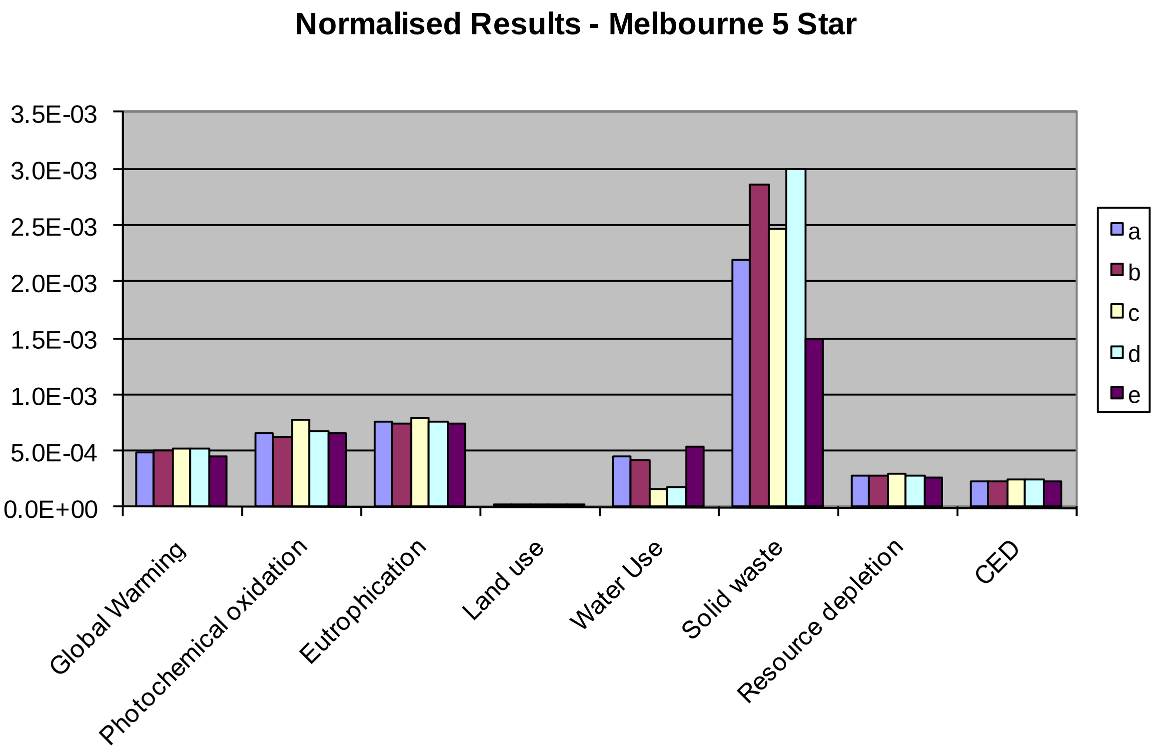


Figure 33 Normalised results for each construction type.

Looking more closely at the results, global warming, photochemical oxidation, eutrophication, resource use and embodied energy show remarkable similarity between the construction types. Land use, water use and solid waste indicators show more pronounced differences between construction types, with water and land use tending to be higher for timber based construction types (a,b and e), and solid waste tending to be higher in concrete slab designs (b and d). Variation between construction types is minimal for most indicators due to the dominance of the operational aspect of the building lifecycle, which contributes 55-86% of global warming impacts. Indicators such as land use, water use and solid waste are less affected by operation so tend to be driven more by construction and end-of-life processes.

Although building operation is still dominant in determining the total building life cycle impact, the study results show construction and materials contributing 14-45% of global warming impacts. This contribution is most significant in the milder climates assessed (Sydney and Brisbane) and increases further as operational impacts are reduced under 6 star performance (17-51%).

The study assumption that each construction type achieve a given energy performance rating effectively removes the effect of energy efficiency as a source of difference between construction types within a given climate zone. The comparative result is therefore driven by the construction and end-of-life impacts associated with the construction type.

<u>Construction and materials in isolation</u>

Comparison of lifecycle impacts excluding operation shows that timber based constructions tend to have lower global warming impacts than alternatives. In general, construction types incorporating timber tend to have lower global warming, resource use and embodied energy outcomes. Figure 20 illustrates this difference, showing construction types incorporating concrete slab floors generate 13% higher global warming impacts versus timber elevated floors and that steel framed construction types generate 21-43% greater global warming impacts versus the equivalent timber framed construction type. In terms of cladding, the brick veneer construction type generated 43% greater global warming impacts than the weatherboard construction type.

For the photochemical oxidation indicator, construction types that incorporated concrete slab floor systems had lower impacts. However, drawing a conclusion regarding the environmental impact of photochemical oxidation is difficult in this study due to the nature of emissions, which in the case of timber, tend to occur in low population areas unlikely to be experiencing smog problems.

Water use and land use to represent key points of differentiation between the construction types considered. In general, water use and land use impacts for each construction type were driven by the timber content. Those construction types that minimise timber use tended to have lower results in these indicators (construction types a,b and e generate 4.5-8.5 times the land use impact and 3.0-3.7 times the water use impact of the equivalent steel framed houses). Although these results suggest significant differences in environmental impacts, the indicators do require interpretation as both indicators are considered ‘provisional’ (Grant and Peters 2008) and reflect simple aggregations of water use and land use without making reference to scarcity or the local environmental impacts of extraction/occupation. Notwithstanding this uncertainty, the large differences seen in these indicators suggest the timber oriented constructions (a,b,e) are more likely to generate greater environmental impact in these areas, however the nature of this impact is unclear.

Eutrophication impacts associated materials and construction were predominantly caused by airborne nitrogen oxide emissions, making it difficult to determine if environmental damage would result in an Australian context. Waterborne emissions, however, were associated predominantly with the timber construction types a, b and c.

<u>Lifecycle comparisons</u>

As mentioned, lifecycle impacts within climate zones tend to be driven by the construction differences discussed, however these are diluted when operational impacts are included. For the global warming indicator, operational impacts represent 55-86% of the life cycle impact of a construction type, diluting construction and material related differences.

Table 38 Summary of construction type comparisons.

	Elevated floor vs concrete slab		Timber frame vs steel frame		Weatherboard vs brick	
	Min	Max	Min	Max	Min	Max
Global Warming	-5%	1%	-17%	-5%	-12%	-5%
Photochemical oxidation	6%	19%	-30%	-10%	-1%	1%
Eutrophication	2%	10%	-13%	-2%	-4%	-4%
Land use	5%	10%	43%	44%	9%	10%
Water Use	-1%	12%	58%	63%	15%	17%
Solid waste	-30%	-20%	-13%	-5%	-47%	-46%
Resource depletion	-1%	6%	-16%	-4%	-12%	-6%
Cumulative Energy Demand	-1%	5%	-12%	-3%	-10%	-5%

Negative indicates former impact less than latter.
Eg Elevated floor better than slab.

Table 38 illustrates the comparative life cycle impacts of construction types incorporating specific building elements. In general, elevated floor designs were shown to have lower global warming impacts than concrete slabs when timber was used, but higher results in other indicators. Elevated floors made from steel tended to have higher impacts than concrete slab designs in most indicators. Timber framing was typically lower for global warming impacts, resource depletion, solid waste and embodied energy, but higher for other indicators such as water use, land use. The construction type incorporating weatherboard cladding tended to have lower results for global warming, solid waste, resource depletion and embodied energy.

In general, Table 38 illustrates lower or neutral global warming, solid waste, resource depletion and embodied energy impacts for construction types incorporating timber elements (elevated floors, timber framing, weatherboard cladding). Other construction types tend to have lower impacts in the other indicators such as photochemical oxidation, eutrophication, land use, water use.

Sensitivity analysis suggests minimal change in study comparative conclusions when housing efficiency is increased from 5 to 6 stars. Of importance is that lifecycle global warming impacts are lowered by 9-17%. House lifetime sensitivities were found to not alter comparative conclusions. End of life assumptions appear to only directionally change conclusions under a '100% recycling' scenario for the photochemical oxidation, water use and land use indicators. In general, 100% recycling reduces solid waste impacts for higher mass construction types, such as type (c) and (d), making them preferable versus the elevated floor designs in this indicator. Water use impacts and photochemical oxidation impacts are reduced for timber intensive designs, making elevated floors preferable, timber walls preferable and timber cladding, in the water use indicator.

Additionally, the Impact 2002+ impact assessment method was found to conclude in a fashion directionally consistent with global warming results shown in this study. The method was found to be applicable to the assessment of constructions, however was considered to be less transparent than a mid-point approach.

Sensitivity analysis also showed no change in conclusions when steel recycling assumptions were altered to assume avoided steel products in accordance with world EAF and BOF steel production.

11.1 Limitations and further work

A key limitation of the study is the characterisation of land use and water use impacts. In order to properly compare building systems and make appropriate decisions during design, users need to be able to accurate rate the relative impacts of systems in these impact categories. Further research into appropriate assessment methods for an Australian environment would significantly improve the quality of LCA in this area.

Construction impacts in this study have been estimated using transport distances and benchmarked against a US study. Accurate building site information, although likely to be a relatively small contributor to lifecycle impacts, is not fully understood. Although impacts are likely to be small versus the building lifecycle, potential for improvement of practices in this area could be significant.

Material recycling data was based on an older study (Crowther (2000)), which in turn was based on a relatively small review of construction practices. Further research in this area would assist LCA development in future.

Documentation of timber LCI when this study was completed was not available. Detailed documentation of the timber LCI will improve the ability of data users to interpret results.

12 References

12.1 SimaPro® background databases utilised

Database name	Description
EcoInvent 2.0	The Ecoinvent 2.0 database contains consistent and transparent, up-to-date Life Cycle Inventory (LCI) data in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment.
Australian Unit Process LCI (AUPLCI) 2009 Edition	Australian LCI database developed from 1998 by Centre for Design at RMIT University from data originally developed with the CRC for Waste Management and Pollution Control, as part of an Australian Inventory data project. The data from this project has been progressively updated, particularly the data for metals production, energy, transport and paper and board production. The inventory is currently published by Lifecycle Strategies (Tim Grant).
IVAM	The IVAM database is a database to be used for environmental life cycle assessment (LCA). It consists of about 1350 processes, leading to more than 350 materials. The data can be used for LCA applications in various sectors. IVAM is the environmental research, training and consultancy firm of the Universiteit van Amsterdam, in environmental aspects of materials. The expertise of IVAM has increased through the LCA's performed. The LCA database was built during these research projects and has continuously been updated.

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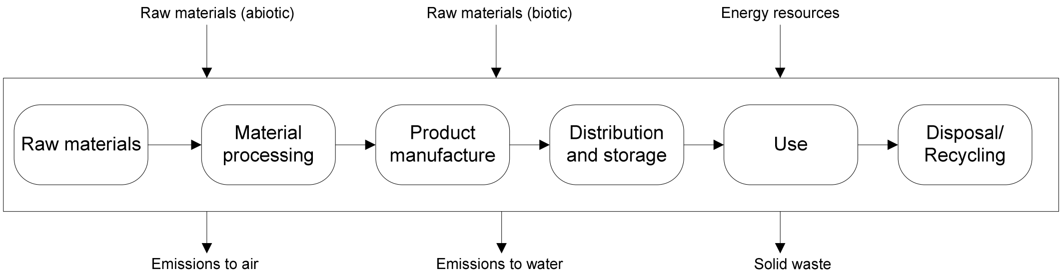
Appendix A Summary of LCA Methodology

The following sections provide a brief description of the LCA methodology. The most important terminology is explained, as well as how to interpret outcomes of the assessment.

Life Cycle Assessment

LCA is the process of evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle. Figure 34 illustrates the life cycle system concept of natural resources and energy entering the system with products, waste and emissions leaving the system.

Figure 34 Life cycle system concept

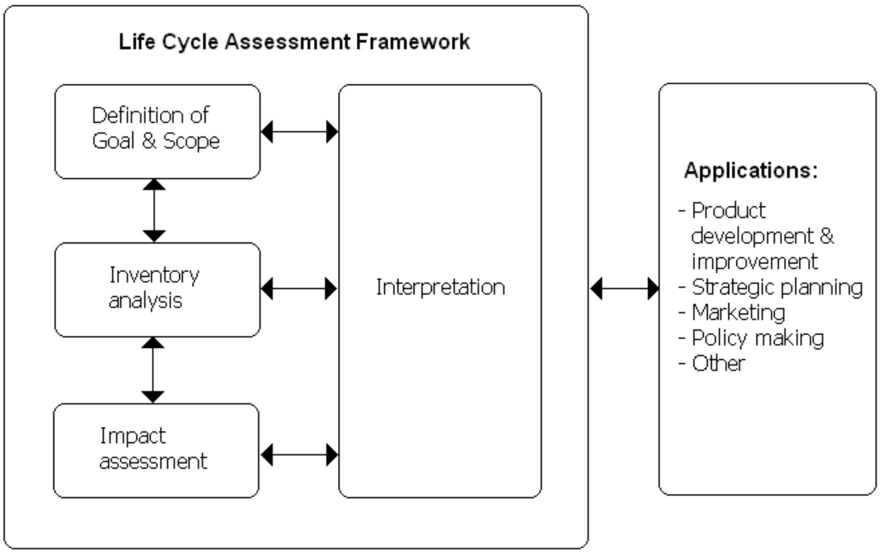


The International Standards Organisation (ISO) has defined LCA as:

> *"[A] Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle" ISO 14040(2006).*

The technical framework for LCA consists of four components, each having a very important role in the assessment. They are interrelated throughout the entire assessment and in accordance with the current terminology of the International Standards Organisation (ISO). The components are goal and scope definition, inventory analysis, impact assessment and interpretation as illustrated in Figure 35.

Figure 35 The Framework for LCA from the International Standard (ISO 14040:2006(E) pp. 8)



Goal and scope definition

At the commencement of an LCA, the goal and scope of the study needs to be clearly defined. The goal should state unambiguously the intended application/purpose of the study, the audience for which the results are intended, the product or function that is to be studied, and the scope of the study.

When defining the scope, consideration of the reference unit, system boundaries and data quality requirements are some of the issues to be covered.

Inventory analysis

Inventory analysis is concerned with the collection, analysis and validation of data that quantifies the appropriate inputs and outputs of a product system. The results include a process flow chart and a list of all emissions and raw material & energy inputs (inventory table) that are associated with the product under study.

Impact assessment

The primary aim of an impact assessment is to identify and establish a link between the product's life cycle and the potential environmental impacts associated with it. The impact assessment stage consists of three phases that are intended to evaluate the significance of the potential environmental effects associated with the product system:

The first phase is the characterisation of the results, assigning the elemental flows to impact categories, and calculating their contribution to that impact.

The second phase is the comparison of the impact results to total national impact levels and is called normalisation.

The third phase is the weighting of these normalised results together to enable the calculation of a single indictor result. In this study, only the first two phases are undertaken.

Interpretation

Interpretation is a systematic evaluation of the outcomes of the life cycle inventory analysis and/or impact assessment, in relation to the goal and scope. This interpretation result into conclusions of the environmental profile of the product or system under investigation, and recommendations on how to improve the environmental profile.

Appendix B Network diagrams

The inventory (Section 6) presents the data sources and assumptions used in modelling the life cycle stages. Most of the data is contained and modelled in LCA software and consists of hundreds of individual unit processes. To help provide transparency to results process trees or network diagrams are used.

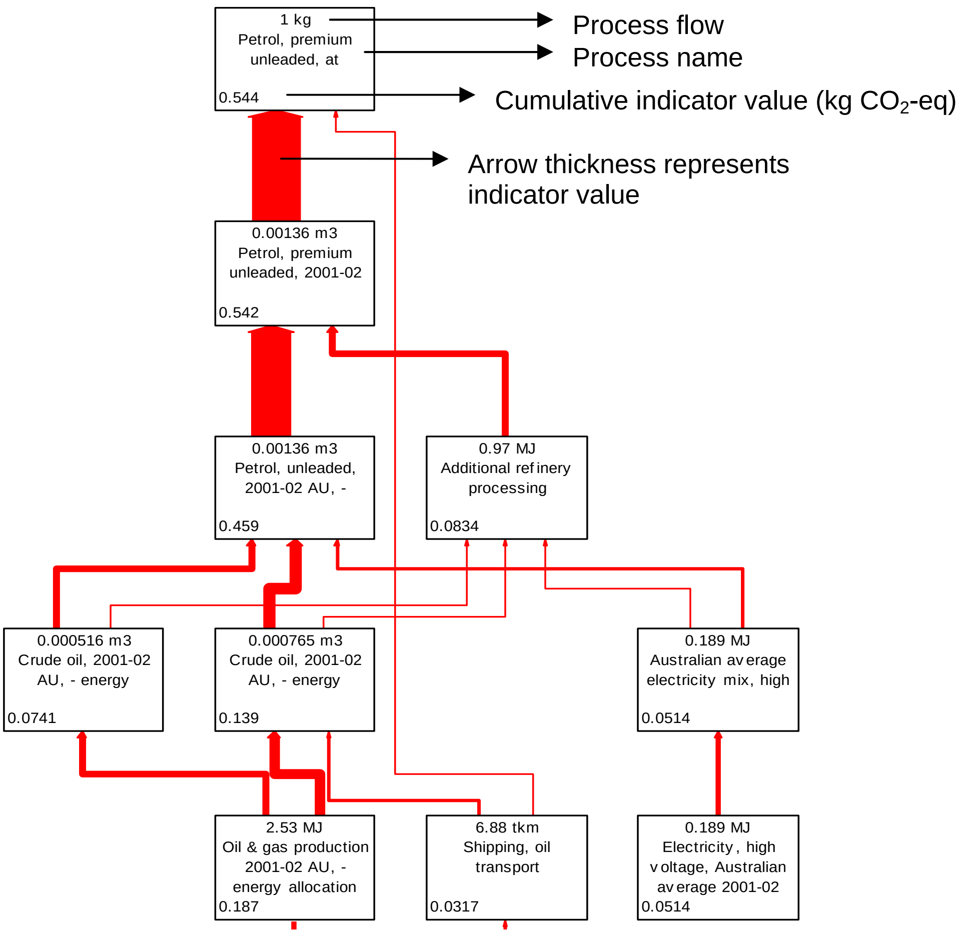
To interpret the network diagram, start at the top of the tree representing the functional output of the process (e.g. petrol premium unleaded, shown in (Figure 36).

The amount and unit of the process is shown in the upper number in the unit process box (1kg). The lower number (in the bottom left hand corner) represents an indicator value which, in this case, is set to show cumulative greenhouse gas contributions in kilograms of equivalent carbon dioxide (CO_2 eq). The arrow thickness represents the indicator value (the thicker the arrow the more impact that process is contributing).

Note that minor processes may not be physically shown in the process network if the indicator value falls below a specific cut-off level, though their contribution to the overall functional unit (the top box in the diagram) is still included. This may mean that manually adding impacts shown on the diagram may not lead to the exact summations shown.

The network diagram may also be truncated at the bottom to improve readability of the networks. Finally, some diagrams may not show the process flows for confidentiality reasons.

Figure 36 Network diagram example.



Appendix C Building sub-assembly material quantity estimates

The following tables summarise material quantity assumptions for the major building sub-assemblies. Material quantities for each sub assembly were multiplied by relevant construction areas, distances or unit quantities described in Table 7 in order to determine the total quantities describe in Table 8.

Table 39 Floor system material quantities per unit of area (based predominantly on Lawson (1996)). Modifications from Lawson highlighted in yellow.

	Quantity	Length	Area	Volume	Unit mass	Unit mass	Unit mass	Density	Mass
	units	m	m2	m3	kg/unit	kg/m	kg/m2	kg/m3	kg
Elevated timber floor/m2									
Bricks 230x110x76 (subfloor wall 0.6m)	12.00			0.02	3.00				36.00
Mortar				0.01				1460.00	8.76
Concrete (footings and stumps)				0.03				2400.00	80.41
Footing reinf	1.00				0.76				0.76
Antcaps			0.01				5.00		0.05
Hardwood bearers 90x70		0.70		0.00				850.00	3.75
Hardwood joists 90x45 (450c-c)		2.40		0.01				850.00	8.26
Particleboard flooring			1.00	0.02				630.00	11.97
Elevated steel floor/m2									
Bricks 230x110x76	12.00			0.02	3.00				36.00
Mortar				0.01				1460.00	8.76
Concrete				0.03				2400.00	80.41
Footing reinf	1.00				0.76				0.76
Antcaps			0.01				5.00		0.05
Steel bearers 150x45x1.6		0.70				4.32			3.02
Steel joists 150x45x1.6		2.40				4.32			10.37
Particleboard flooring			1.00	0.02				630.00	11.97
Elevated timber floor/m2 (weatherboard)									
Softwood weatherboards 200x20			0.20	0.00				550.00	2.10
Polystyrene substrate 60mm				0.01				19.00	0.23
Concrete (stumps)				0.01				2400.00	20.02
Antcaps			0.01				5.00		0.05
Hardwood bearers 90x70		0.70		0.00				850.00	3.75
Hardwood joists 90x45 (450c-c)		2.40		0.01				850.00	8.26
Particleboard flooring			1.00	0.02				630.00	11.97
110mm concrete slab on ground/m2									
Concrete (incl edge and internal beam)				0.16				2400.00	394.85
Steel reinforcement mesh F72 in top			1.00				2.80		2.80
Edge beam reinforecement 3/8TM		0.40				1.33			0.53
Internal beam reinf	1.00				1.41				1.41
Edge beam ligatures 6mm wire		1.00				0.23			0.23
Waterproof membrane 3 micron			1.00				0.27		0.27

Table 40 Wall and structure system material quantities per unit of area (based predominantly on Lawson (1996)). Modifications from Lawson highlighted in yellow.

	Quantity	Length	Area	Volume	Unit mass	Unit mass	Unit mass	Density	Mass
	units	m	m2	m3	kg/unit	kg/m	kg/m2	kg/m3	kg
Timber frame, clay brick veneer wall/m2									
Softwood studs 90x35		2.60		0.01				550.00	4.50
Softwood plates 90x45		1.00		0.00				550.00	2.23
Softwood noggings 90x35		0.40		0.00				550.00	0.69
Bricks 230x110x76	49.00		1.00	0.09	3.00				147.00
Mortar				0.02				1460.00	25.11
Aluminium flashing 150mm			0.15				1.30		0.20
Polyethylene dpc 0.5gauge			0.06				0.49		0.03
Wall ties	3.00				0.05				0.14
Sarking			1.00				0.29		0.29
Plasterboard			1.00				7.10		7.10
Paint			1.00				0.24		0.24
Steel frame, clay brick veneer wall/m2									
Steel studs 0.95mm gauge		2.60				1.31			3.42
Steel plates 0.95mm gauge		1.00				1.31			1.31
Steel noggings 0.95mm gauge		0.40				1.31			0.53
Bricks 230x110x76	49.00		1.00	0.09	3.00				147.00
Mortar				0.02				1460.00	25.11
Aluminium flashing 150mm			0.15				1.30		0.20
Polyethylene dpc 0.5gauge			0.06				0.49		0.03
Wall ties	3.00				0.05				0.14
Sarking			1.00				0.29		0.29
Plasterboard			1.00				7.10		7.10
Paint			1.00				0.24		0.24
Timber frame, timber WB wall/m2									
Softwood studs 90x35		2.60		0.01				550.00	4.50
Softwood plates 90x45		1.00		0.00				550.00	2.23
Softwood noggings 90x35		0.40		0.00				550.00	0.69
Softwood weatherboards 200x20		5.00		0.02				550.00	10.45
Aluminium flashing 150mm			0.08				1.30		0.10
Polyethylene dpc 0.5gauge			0.06				0.49		0.03
Sarking			1.00				0.29		0.29
Plasterboard			1.00				7.10		7.10
Paint			1.00				0.24		0.24
Structural									
Lintels (150x90x10) (steel)		1.00				18.70			18.70
Parallel flange beam (230x75) (steel)		1.00				25.00			25.00
Timber lintel 2x290x45 (F17)		1.00		0.03				850.00	22.19
Timber frame, internal wall/m2									
Softwood studs 90x35		2.60		0.01				550.00	4.50
Softwood plates 90x45		1.00		0.00				550.00	1.73
Softwood noggings 90x35		0.40		0.00				550.00	0.69
Plasterboard			2.00				7.10		14.20
Paint			2.00				0.24		0.49
Steel frame, internal wall/m2									
Steel studs 0.95mm gauge		2.60				1.31			3.42
Steel plates 0.95mm gauge		1.00				1.31			1.31
Steel noggings 0.95mm gauge		0.40				1.31			0.53
Plasterboard			2.00				7.10		14.20
Paint			2.00				0.24		0.49

Table 41 Roof system material quantities per unit of area (based predominantly on Lawson (1996)). Modifications from Lawson highlighted in yellow.

	Quantity	Length	Area	Volume	Unit mass	Unit mass	Unit mass	Density	Mass
	units	m	m2	m3	kg/unit	kg/m	kg/m2	kg/m3	kg
Timber frame, concrete tile roof/m2									
Softwood trusses 90x45		4.60		0.02				550.00	10.25
Hardwood battens 35x50		3.16		0.01				850.00	4.70
Concrete tiles			1.00				52.00		52.00
Sarking			1.00				0.29		0.29
Plasterboard lining			1.00				7.10		7.10
Paint			1.13				0.24		0.28
Fibre cement eave			0.13				8.10		1.05
Steel frame, concrete tile roof/m2									
Steel trusses 1mm gauge		4.60				1.11			5.11
Steel battens 20mm		3.16				0.27			0.85
Concrete tiles			1.00				52.00		52.00
Sarking			1.00				0.29		0.29
Steel ceiling battens		1.87				0.51			0.95
Plasterboard lining			1.00				7.10		7.10
Paint			1.13				0.24		0.28
Fibre cement eave			0.13				8.10		1.05
Timber frame, steel sheet roof/m2									
Softwood trusses 90x45		3.00		0.01				550.00	6.68
Hardwood battens 35x75		1.30		0.00				850.00	2.90
Steel roofing 0.5mm			1.00				4.90		4.90
Sarking			1.00				0.29		0.29
Softwood ceiling battens 25x40		2.20		0.00				550.00	1.21
Plasterboard lining			1.00				7.10		7.10
Paint			1.00				0.24		0.24
Steel frame, steel sheet roof/m2									
Steel trusses 1mm gauge		3.00				1.11			3.33
Steel battens 0.6mm gauge		1.30				0.58			0.75
Steel roofing 0.5mm			1.00				4.90		4.90
Sarking			1.00				0.29		0.29
Steel ceiling battens		1.87				0.51			0.95
Plasterboard lining			1.00				7.10		7.10
Paint			1.00				0.24		0.24

Table 42 Other system material quantities per unit of area/distance developed specifically for this study.

	Quantity	Length	Area	Volume	Unit mass	Unit mass	Unit mass	Density	Mass
	units	m	m2	m3	kg/unit	kg/m	kg/m2	kg/m3	kg
Window, timber frame, 6.38 lam glass/m2									
Glass 6.68mm			1.00				16.00		16.00
Timber (hardwood)				0.01				850.00	12.33
Doors, per door									
Entry (hardwood)				0.07				850.00	56.88
Interior (particle board)				0.07				630.00	41.58
Garage door (steel sheet)			14.00				4.90		68.60
Pergola, per m2									
Timber (softwood)				0.03				550.00	16.50
Concrete									16.00
Steel									0.31
Awnings, per m2									
Polyester fabric			1.20				0.34		0.41
Steel									2.50

Appendix D Material quantity benchmarking

In order to validate the quantities developed (based on an adjusted version of Lawson (1996)), independent estimates were sought and compared. Comparisons drawn were as follows.

Table 43 compares the study quantities used for construction type b to quantities developed for the HIA home used in the study (HIA 2009), a ‘first principles’ calculation of concrete in a ‘waffle pod’ slab design by the author and a scaled estimate from a contemporary two storey design (Davis Langdon 2009).

Table 43 Brick veneer, timber frame, concrete slab construction material quantity comparison.

		Brick veneer, timber frame, slab			
		This study (Construction type b)	Quanities developed to cost HIA home used in this study (Cordell costing study)	Waffle pod estimate (undertaken by author)	Scaled quanitities from contemporary two story home (Davis Langdon materials estimate)
Hardwood (battens, joists, bearers)	m3	1.7	0.9		
Softwood frame	m3	7.0	5.9		7.9
Reinforcing steel (concrete)	kg	1000.9	813.0	1134.2	1843.7
Structural steel (lintels, beams)	kg	169.9	170.0		
Sheet steel (roof)	kg	281.6	233.1		
Concrete	m3	33.2	33.6	32.0	37.2
Mortar	kg	2682.6			
Brick	units	5234.4	5251.0		
Plasterboard	m2	615.4	512.8		
Tiles	kg	9445.8	9190.2		
Fibre cement sheet	m2	23.6	22.3		
Other	kg	333.0			

Table 44 compares the study quantities used for a construction type a to quantities published in an older textbook (Bloomfield and Peterson 1985).

Table 44 Brick veneer, timber frame, elevated floor construction material quantity comparison

		Brick veneer, timber frame, elevated floor	
		This study (Construction type a)	Scaled quantities from textbook (Bloomfield (1985))
Hardwood (battens, joists, bearers)	m3	4.0	4.1
Softwood frame	m3	7.0	13.8
Reinforcing steel (concrete)	kg	336.0	
Structural steel (lintels, beams)	kg	169.9	
Sheet steel (roof)	kg	281.6	
Concrete	m3	12.4	8.8
Mortar	kg	4068.0	
Brick	units	7132.2	10607.5
Particleboard	m2	158.2	
Plasterboard	m2	615.4	550.5
Tiles	kg	9445.8	
Fibre cement sheet	m2	23.6	
Other	kg	298.3	

Table 45 and Table 46 compare construction types c and d to steel quantities estimated from ‘first principles’ for the design used in this study by an independent third party estimator. Note that the elevated floor design assumes steel stumps, whereas this study uses concrete stumps (Table 45).

Table 45 Brick veneer, steel frame, elevated floor construction material quantity comparison

		Brick veneer, steel frame, elevated floor	
		This study (Construction type c)	Estimate for study building developed by independent party
Framing steel	kg	4790.9	5390.0
Reinforcing steel (concrete)	kg	336.0	
Structural steel (lintels, beams)	kg	169.9	
Sheet steel (roof)	kg	281.6	
Concrete	m3	12.4	
Mortar	kg	4068.0	
Brick	units	7132.2	
Particleboard	m2	158.2	
Plasterboard	m2	615.4	
Tiles	kg	9445.8	
Fibre cement sheet	m2	23.6	
Other	kg	298.3	

Table 46 Brick veneer, steel frame, concrete slab construction material quantity comparison

		Brick veneer, steel frame, slab	
		This study (Construction type d)	Estimate for study building developed by independent party
Framing steel	kg	2673.0	2770.0
Reinforcing steel (concrete)	kg	1000.9	
Structural steel (lintels, beams)	kg	169.9	
Sheet steel (roof)	kg	281.6	
Concrete	m3	33.2	
Mortar	kg	2682.6	
Brick	units	5234.4	
Particleboard	m2	0.0	
Plasterboard	m2	615.4	
Tiles	kg	9445.8	
Fibre cement sheet	m2	23.6	
Other	kg	333.0	

An independent validation of weatherboard quantities was not available, however checks were undertaken with reference group participants with relevant expertise.

Appendix E AccuRate energy modelling results.

Table 47 Energy modelling results for construction types – 5 star

		a	b	c	d	e	Average
Melbourne							
Conditioned floor area	m2	151.2	151.2	151.2	151.2	151.2	
Total floor area (including garage)	m2	201.6	201.6	201.6	201.6	201.6	
Rating	stars	5.1	4.9	5.1	4.9	5.0	
Area adjusted energy requirements							
Heating	MJ/m2	110.9	111.7	110.9	111.7	109.8	
Cooling (sensible)	MJ/m2	30.9	38.8	30.9	38.8	35.8	
Cooling (latent)	MJ/m2	3.0	3.1	3.0	3.1	3.0	
Total	MJ/m2	144.8	153.6	144.8	153.6	148.6	
Percentage heating		77%	73%	77%	73%	74%	75%
Star band	MJ/m2	149	149	149	149	149	149
Normalised heating/cooling requirements							
Heating	MJ/m2	114.1	108.4	114.1	108.4	110.1	111.0
Cooling	MJ/m2	34.9	40.6	34.9	40.6	38.9	38.0
Total	MJ/m2	149.0	149.0	149.0	149.0	149.0	149.0
Normalised heating/cooling requirements per functional unit							
Heating	MJ/m2	85.6	81.3	85.6	81.3	82.6	
Cooling	MJ/m2	26.2	30.5	26.2	30.5	29.2	
Total	MJ/m2	111.7	111.7	111.7	111.7	111.7	
Sydney							
Conditioned floor area	m2	151.2	151.2	151.2	151.2	151.2	
Total floor area (including garage)	m2	201.6	201.6	201.6	201.6	201.6	
Rating	stars	5.1	5.0	5.1	5.0	5.0	
Area adjusted energy requirements							
Heating	MJ/m2	20.9	19.2	20.9	19.2	22.3	
Cooling (sensible)	MJ/m2	19.7	22.0	19.7	22.0	18.9	
Cooling (latent)	MJ/m2	8.6	8.6	8.6	8.6	8.5	
Total	MJ/m2	49.2	49.8	49.2	49.8	49.7	
Percentage heating		42%	39%	42%	39%	45%	41%
Star band	MJ/m2	50	50	50	50	50	50
Normalised heating/cooling requirements							
Heating	MJ/m2	21.2	19.3	21.2	19.3	22.4	20.7
Cooling	MJ/m2	28.8	30.7	28.8	30.7	27.6	29.3
Total	MJ/m2	50.0	50.0	50.0	50.0	50.0	50.0
Normalised heating/cooling requirements per functional unit							
Heating	MJ/m2	15.9	14.5	15.9	14.5	16.8	
Cooling	MJ/m2	21.6	23.0	21.6	23.0	20.7	
Total	MJ/m2	37.5	37.5	37.5	37.5	37.5	
Brisbane							
Conditioned floor area	m2	151.2	151.2	151.2	151.2	151.2	
Total floor area (including garage)	m2	201.6	201.6	201.6	201.6	201.6	
Rating	stars	5.1	5.1	5.1	5.1	4.9	
Area adjusted energy requirements							
Heating	MJ/m2	15.1	11.9	15.1	11.9	16.7	
Cooling (sensible)	MJ/m2	23.3	25.6	23.3	25.6	23.7	
Cooling (latent)	MJ/m2	15.3	15.6	15.3	15.6	15.6	
Total	MJ/m2	53.7	53.1	53.7	53.1	56	
Percentage heating		28%	22%	28%	22%	30%	26%
Star band	MJ/m2	55	55	55	55	55	55
Normalised heating/cooling requirements							
Heating	MJ/m2	15.5	12.3	15.5	12.3	16.4	14.4
Cooling	MJ/m2	39.5	42.7	39.5	42.7	38.6	40.6
Total	MJ/m2	55.0	55.0	55.0	55.0	55.0	55.0
Normalised heating/cooling requirements per functional unit							
Heating	MJ/m2	11.6	9.2	11.6	9.2	12.3	
Cooling	MJ/m2	29.6	32.0	29.6	32.0	28.9	
Total	MJ/m2	41.2	41.2	41.2	41.2	41.2	

Table 48 AccuRate energy modelling results for construction types - 6 star

		a	b	c	d	e	Average
Melbourne							
Conditioned floor area	m2	151.2	151.2	151.2	151.2	151.2	
Total floor area (including garage)	m2	201.6	201.6	201.6	201.6	201.6	
Rating	stars	6.0	6.1	6.0	6.1	6.0	
Area adjusted energy requirements							
Heating	MJ/m2	73.7	85.5	73.7	85.5	81.2	
Cooling (sensible)	MJ/m2	36.2	23.0	36.2	23.0	28.5	
Cooling (latent)	MJ/m2	3.3	2.7	3.3	2.7	3.2	
Total	MJ/m2	113.2	111.2	113.2	111.2	112.9	
Percentage heating		65%	77%	65%	77%	72%	71%
Star band	MJ/m2	114	114	114	114	114	114
Normalised heating/cooling requirements							
Heating	MJ/m2	74.2	87.7	74.2	87.7	82.0	81.1
Cooling	MJ/m2	39.8	26.3	39.8	26.3	32.0	32.9
Total	MJ/m2	114.0	114.0	114.0	114.0	114.0	114.0
Normalised heating/cooling requirements per functional unit							
Heating	MJ/m2	55.7	65.7	55.7	65.7	61.5	60.9
Cooling	MJ/m2	29.8	19.8	29.8	19.8	24.0	24.6
Total	MJ/m2	85.5	85.5	85.5	85.5	85.5	85.5
Sydney							
Conditioned floor area	m2	151.2	151.2	151.2	151.2	151.2	
Total floor area (including garage)	m2	201.6	201.6	201.6	201.6	201.6	
Rating	stars	5.9	5.9	5.9	5.9	5.9	
Area adjusted energy requirements							
Heating	MJ/m2	15.7	16.8	15.7	16.8	16.4	
Cooling (sensible)	MJ/m2	15.4	15.1	15.4	15.1	15.7	
Cooling (latent)	MJ/m2	8.2	7.6	8.2	7.6	8.2	
Total	MJ/m2	39.3	39.5	39.3	39.5	40.3	
Percentage heating		40%	43%	40%	43%	41%	41%
Star band	MJ/m2	39	39	39	39	39	39
Normalised heating/cooling requirements							
Heating	MJ/m2	15.6	16.6	15.6	16.6	15.9	16.0
Cooling	MJ/m2	23.4	22.4	23.4	22.4	23.1	23.0
Total	MJ/m2	39.0	39.0	39.0	39.0	39.0	39.0
Normalised heating/cooling requirements per functional unit							
Heating	MJ/m2	11.7	12.4	11.7	12.4	11.9	12.0
Cooling	MJ/m2	17.6	16.8	17.6	16.8	17.3	17.2
Total	MJ/m2	29.2	29.2	29.2	29.2	29.2	29.2
Brisbane							
Conditioned floor area	m2	151.2	151.2	151.2	151.2	151.2	
Total floor area (including garage)	m2	201.6	201.6	201.6	201.6	201.6	
Rating	stars	6.1	6.0	6.1	6.0	5.9	
Area adjusted energy requirements							
Heating	MJ/m2	10.0	7.1	10.0	7.1	10.1	
Cooling (sensible)	MJ/m2	18.0	20.9	18.0	20.9	19.2	
Cooling (latent)	MJ/m2	14.2	14.6	14.2	14.6	14.4	
Total	MJ/m2	42.2	42.6	42.2	42.6	43.7	
Percentage heating		24%	17%	24%	17%	23%	21%
Star band	MJ/m2	43	43	43	43	43	43
Normalised heating/cooling requirements							
Heating	MJ/m2	10.2	7.2	10.2	7.2	9.9	8.9
Cooling	MJ/m2	32.8	35.8	32.8	35.8	33.1	34.1
Total	MJ/m2	43.0	43.0	43.0	43.0	43.0	43.0
Normalised heating/cooling requirements per functional unit							
Heating	MJ/m2	7.6	5.4	7.6	5.4	7.5	6.7
Cooling	MJ/m2	24.6	26.9	24.6	26.9	24.8	25.6
Total	MJ/m2	32.2	32.2	32.2	32.2	32.2	32.2

Appendix F Normalised results

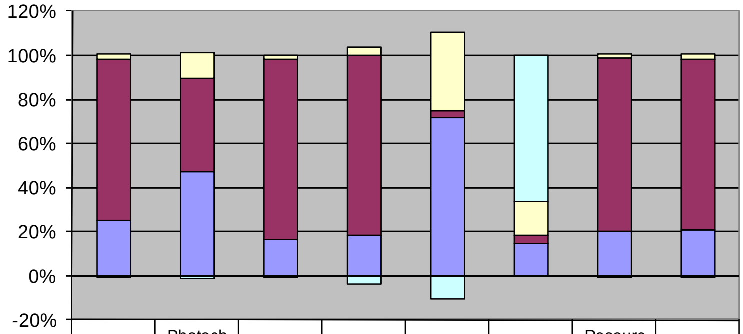
Table 49 Normalised results for the life cycle (5 star)

Melbourne		a	b	c	d	e
Global Warming		4.8E-04	5.0E-04	5.2E-04	5.2E-04	4.6E-04
Photochemical oxidation		6.6E-04	6.2E-04	7.8E-04	6.8E-04	6.5E-04
Eutrophication		7.6E-04	7.4E-04	8.0E-04	7.6E-04	7.3E-04
Land use		9.0E-06	8.5E-06	5.1E-06	4.8E-06	9.9E-06
Water Use		4.6E-04	4.1E-04	1.7E-04	1.7E-04	5.5E-04
Solid waste		2.2E-03	2.9E-03	2.5E-03	3.0E-03	1.5E-03
Resource depletion		2.8E-04	2.8E-04	3.0E-04	2.9E-04	2.6E-04
CED		2.4E-04	2.4E-04	2.5E-04	2.4E-04	2.3E-04
Sydney						
Global Warming		2.4E-04	2.5E-04	2.8E-04	2.8E-04	2.1E-04
Photochemical oxidation		4.2E-04	3.8E-04	5.4E-04	4.5E-04	4.2E-04
Eutrophication		2.7E-04	2.7E-04	3.1E-04	2.8E-04	2.6E-04
Land use		9.0E-06	8.5E-06	5.1E-06	4.8E-06	1.0E-05
Water Use		4.6E-04	4.1E-04	1.7E-04	1.7E-04	5.5E-04
Solid waste		2.2E-03	2.8E-03	2.5E-03	3.0E-03	1.5E-03
Resource depletion		1.1E-04	1.1E-04	1.3E-04	1.2E-04	9.9E-05
CED		1.0E-04	1.0E-04	1.2E-04	1.1E-04	9.4E-05
Brisbane						
Global Warming		2.6E-04	2.7E-04	3.0E-04	3.0E-04	2.3E-04
Photochemical oxidation		4.2E-04	3.8E-04	5.5E-04	4.5E-04	4.2E-04
Eutrophication		2.6E-04	2.5E-04	3.0E-04	2.7E-04	2.5E-04
Land use		9.2E-06	8.5E-06	5.3E-06	4.8E-06	1.0E-05
Water Use		4.7E-04	4.1E-04	1.8E-04	1.7E-04	5.6E-04
Solid waste		2.2E-03	2.9E-03	2.5E-03	3.0E-03	1.5E-03
Resource depletion		1.1E-04	1.1E-04	1.3E-04	1.2E-04	1.0E-04
CED		1.1E-04	1.1E-04	1.2E-04	1.1E-04	9.7E-05

Appendix G Life cycle impact breakdown

Melbourne

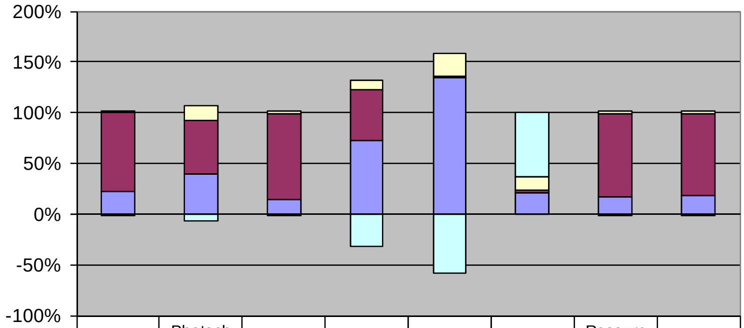
Lifecycle impact Drivers - House (c) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-1%	-1%	0%	-3%	-11%	66%	-1%	-1%
Maintenance	3%	12%	2%	3%	36%	15%	2%	2%
Operation	73%	42%	82%	82%	3%	3%	79%	78%
Materials & constr.	25%	47%	16%	18%	72%	15%	20%	21%

End of life · Maintenance · Operation · Materials & constr.

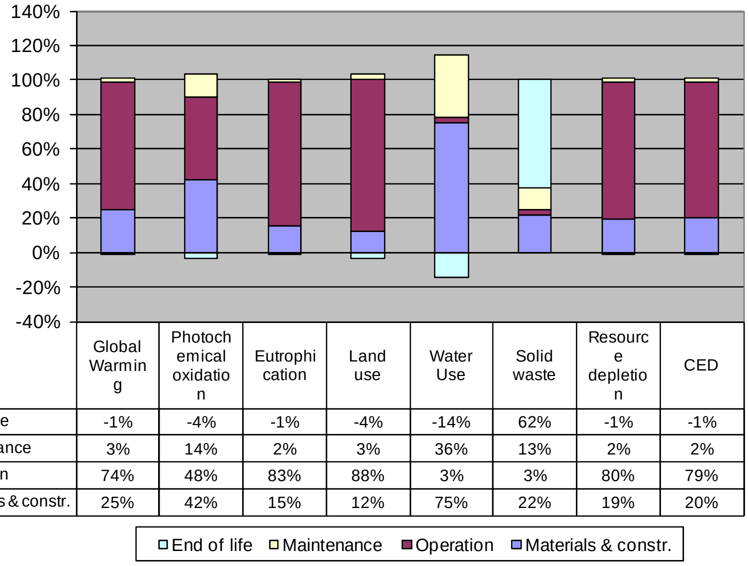
Lifecycle impact Drivers - House (b) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-6%	-1%	-32%	-59%	63%	-1%	-1%
Maintenance	2%	14%	2%	9%	22%	13%	2%	2%
Operation	77%	53%	85%	50%	1%	3%	82%	81%
Materials & constr.	22%	39%	14%	73%	135%	21%	17%	18%

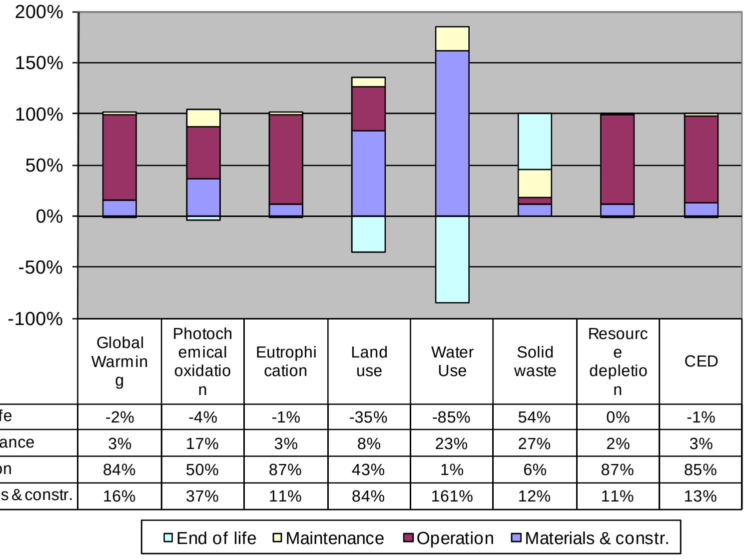
End of life · Maintenance · Operation · Materials & constr.

Lifecycle impact Drivers - House (d) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-1%	-4%	-1%	-4%	-14%	62%	-1%	-1%
Maintenance	3%	14%	2%	3%	36%	13%	2%	2%
Operation	74%	48%	83%	88%	3%	3%	80%	79%
Materials & constr.	25%	42%	15%	12%	75%	22%	19%	20%

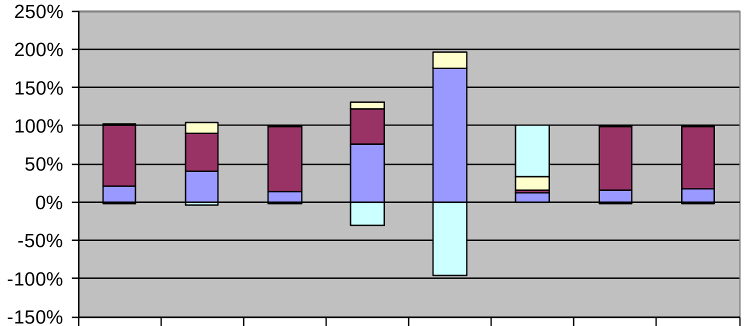
Lifecycle impact Drivers - House (e) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-4%	-1%	-35%	-85%	54%	0%	-1%
Maintenance	3%	17%	3%	8%	23%	27%	2%	3%
Operation	84%	50%	87%	43%	1%	6%	87%	85%
Materials & constr.	16%	37%	11%	84%	161%	12%	11%	13%

Sydney

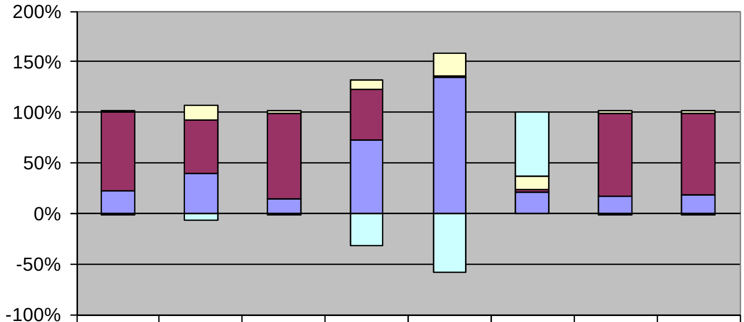
Lifecycle impact Drivers - House (a) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-4%	-1%	-31%	-96%	67%	-1%	-1%
Maintenance	2%	14%	2%	8%	20%	17%	2%	2%
Operation	79%	51%	86%	47%	1%	4%	84%	82%
Materials & constr.	21%	40%	13%	75%	175%	12%	15%	17%

End of life, Maintenance, Operation, Materials & constr.

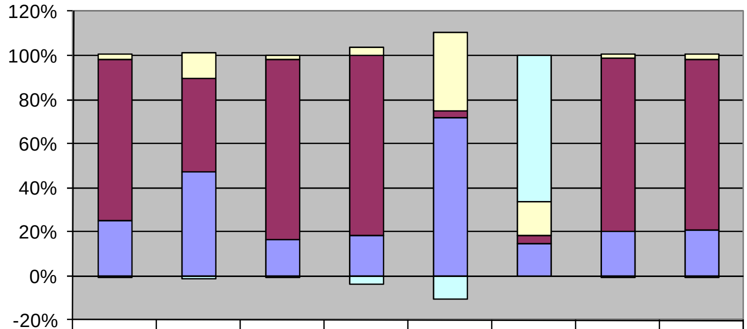
Lifecycle impact Drivers - House (b) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-6%	-1%	-32%	-59%	63%	-1%	-1%
Maintenance	2%	14%	2%	9%	22%	13%	2%	2%
Operation	77%	53%	85%	50%	1%	3%	82%	81%
Materials & constr.	22%	39%	14%	73%	135%	21%	17%	18%

End of life, Maintenance, Operation, Materials & constr.

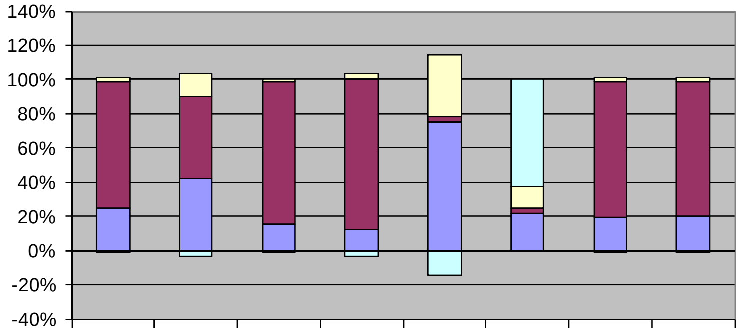
Lifecycle impact Drivers - House (c) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-1%	-1%	0%	-3%	-11%	66%	-1%	-1%
Maintenance	3%	12%	2%	3%	36%	15%	2%	2%
Operation	73%	42%	82%	82%	3%	3%	79%	78%
Materials & constr.	25%	47%	16%	18%	72%	15%	20%	21%

End of life   Maintenance   Operation   Materials & constr.

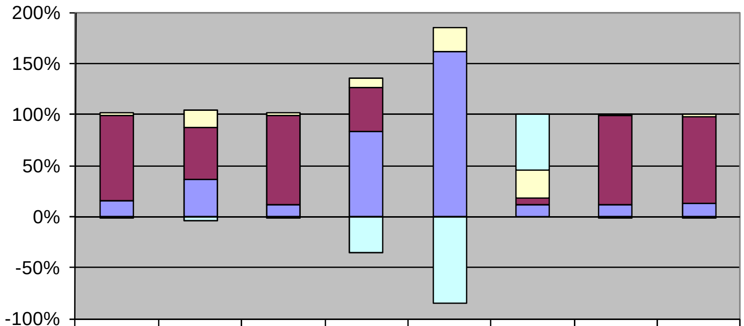
Lifecycle impact Drivers - House (d) - Melbourne - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-1%	-4%	-1%	-4%	-14%	62%	-1%	-1%
Maintenance	3%	14%	2%	3%	36%	13%	2%	2%
Operation	74%	48%	83%	88%	3%	3%	80%	79%
Materials & constr.	25%	42%	15%	12%	75%	22%	19%	20%

End of life   Maintenance   Operation   Materials & constr.

Lifecycle impact Drivers - House (e) - Melbourne - 5 star

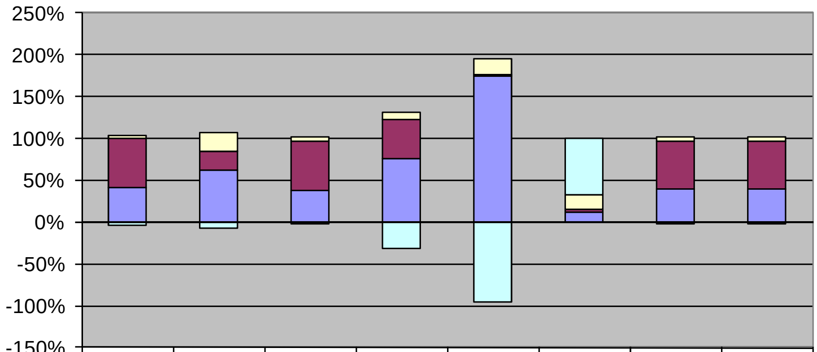


	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-4%	-1%	-35%	-85%	54%	0%	-1%
Maintenance	3%	17%	3%	8%	23%	27%	2%	3%
Operation	84%	50%	87%	43%	1%	6%	87%	85%
Materials & constr.	16%	37%	11%	84%	161%	12%	11%	13%

End of life Maintenance Operation Materials & constr.

Sydney

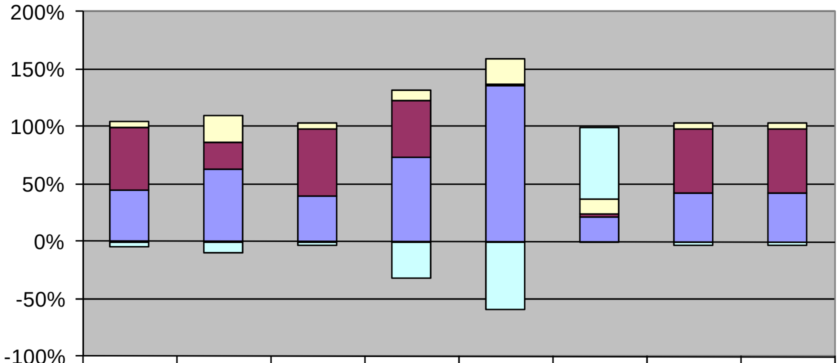
Lifecycle impact Drivers - House (a) - Sydney - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-4%	-6%	-3%	-31%	-96%	67%	-2%	-2%
Maintenance	5%	21%	6%	8%	20%	17%	5%	5%
Operation	58%	22%	59%	47%	1%	3%	58%	57%
Materials & constr.	42%	63%	37%	75%	175%	12%	39%	40%

End of life Maintenance Operation Materials & constr.

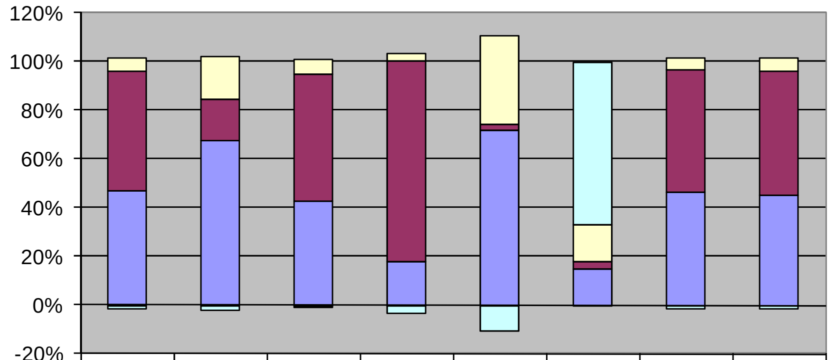
Lifecycle impact Drivers - House (b) - Sydney - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-4%	-10%	-4%	-32%	-59%	63%	-3%	-3%
Maintenance	5%	23%	6%	9%	23%	13%	4%	5%
Operation	55%	24%	58%	50%	1%	3%	57%	56%
Materials & constr.	44%	63%	40%	73%	136%	21%	42%	42%

End of life Maintenance Operation Materials & constr.

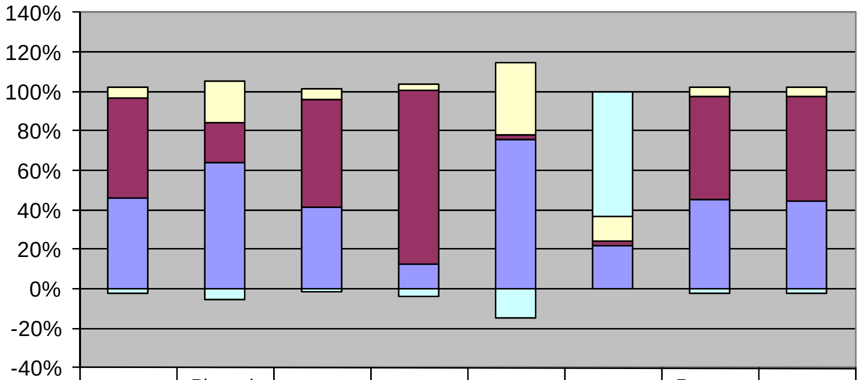
Lifecycle impact Drivers - House (c) - Sydney - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-1%	-2%	-1%	-3%	-11%	67%	-1%	-1%
Maintenance	5%	17%	6%	3%	36%	15%	5%	5%
Operation	49%	17%	52%	82%	2%	3%	50%	51%
Materials & constr.	47%	68%	43%	18%	72%	15%	46%	45%

End of life Maintenance Operation Materials & constr.

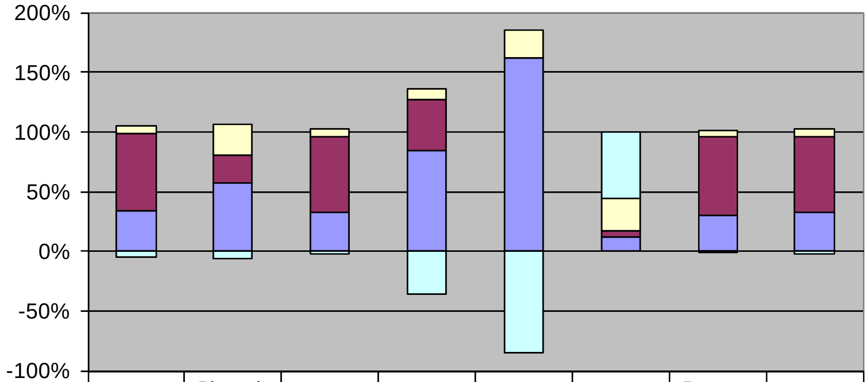
Lifecycle impact Drivers - House (d) - Sydney - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-5%	-2%	-4%	-14%	63%	-3%	-2%
Maintenance	5%	21%	6%	3%	36%	13%	5%	5%
Operation	51%	20%	54%	88%	2%	2%	52%	53%
Materials & constr.	46%	64%	41%	12%	76%	22%	46%	44%

End of life, Maintenance, Operation, Materials & constr.

Lifecycle impact Drivers - House (e) - Sydney - 5 star

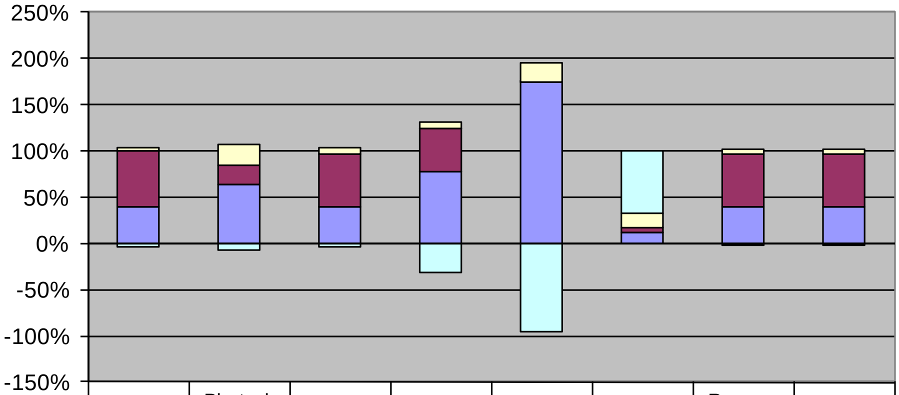


	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-5%	-6%	-3%	-35%	-85%	56%	-1%	-2%
Maintenance	6%	26%	7%	8%	23%	28%	6%	6%
Operation	65%	22%	63%	42%	1%	4%	66%	63%
Materials & constr.	34%	58%	33%	85%	161%	12%	30%	32%

End of life, Maintenance, Operation, Materials & constr.

Brisbane

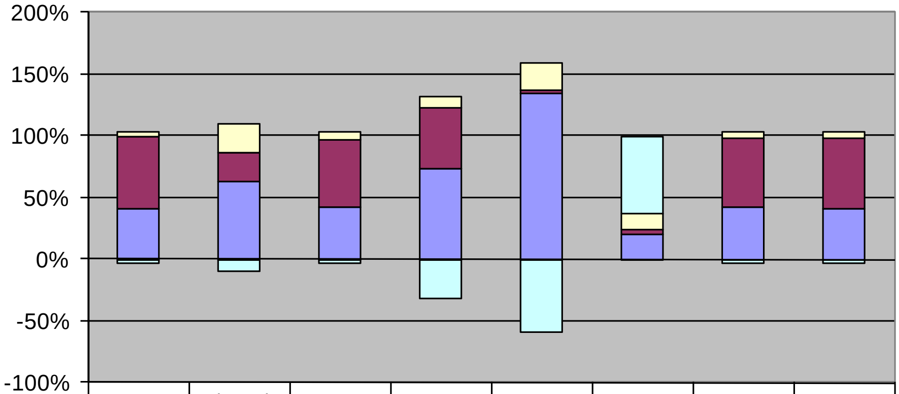
Lifecycle impact Drivers - House (a) - Brisbane - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-4%	-6%	-3%	-32%	-95%	67%	-2%	-2%
Maintenance	4%	21%	6%	8%	20%	17%	4%	5%
Operation	61%	22%	58%	46%	1%	4%	58%	58%
Materials & constr.	39%	63%	39%	77%	174%	12%	39%	39%

End of life Maintenance Operation Materials & constr.

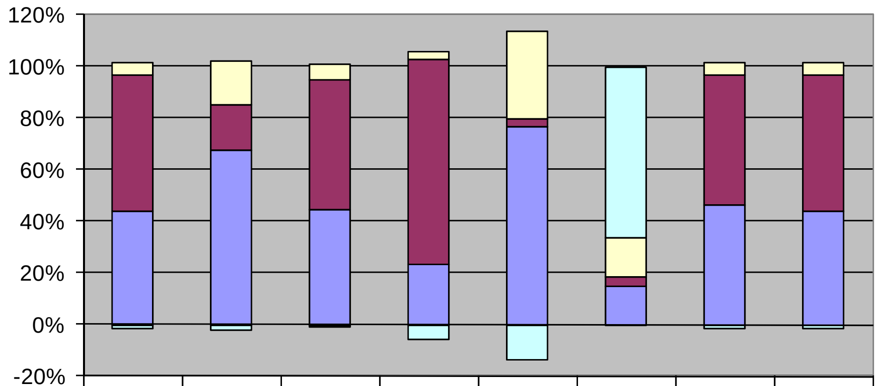
Lifecycle impact Drivers - House (b) - Brisbane - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-4%	-10%	-4%	-32%	-59%	63%	-3%	-3%
Maintenance	4%	23%	6%	9%	22%	13%	4%	5%
Operation	59%	24%	56%	50%	1%	4%	56%	57%
Materials & constr.	41%	63%	42%	73%	135%	21%	42%	41%

End of life Maintenance Operation Materials & constr.

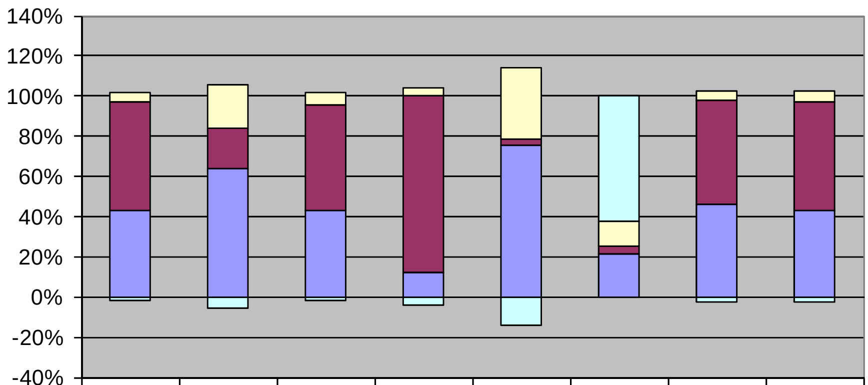
Lifecycle impact Drivers - House (c) - Brisbane - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-1%	-2%	-1%	-6%	-14%	66%	-1%	-1%
Maintenance	5%	17%	6%	3%	34%	15%	5%	5%
Operation	53%	17%	51%	79%	3%	4%	50%	52%
Materials & constr.	44%	68%	44%	24%	77%	15%	46%	44%

End of life Maintenance Operation Materials & constr.

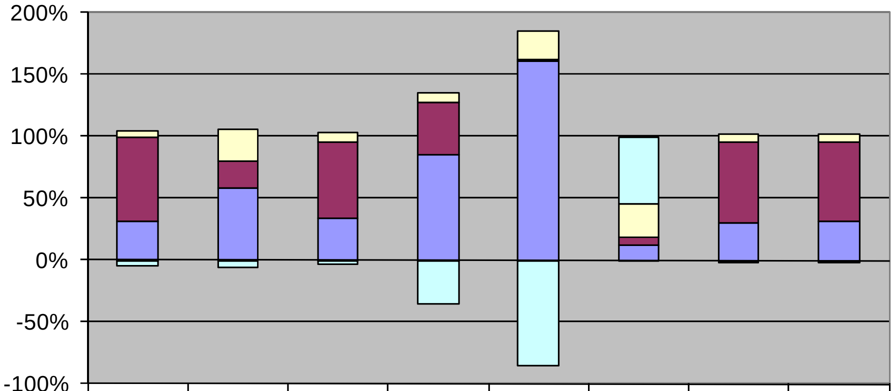
Lifecycle impact Drivers - House (d) - Brisbane - 5 star



	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-2%	-5%	-2%	-4%	-14%	62%	-3%	-2%
Maintenance	5%	21%	7%	3%	36%	13%	5%	5%
Operation	54%	20%	52%	88%	3%	3%	52%	54%
Materials & constr.	43%	64%	43%	12%	75%	22%	46%	43%

End of life Maintenance Operation Materials & constr.

Lifecycle impact Drivers - House (e) - Brisbane - 5 star

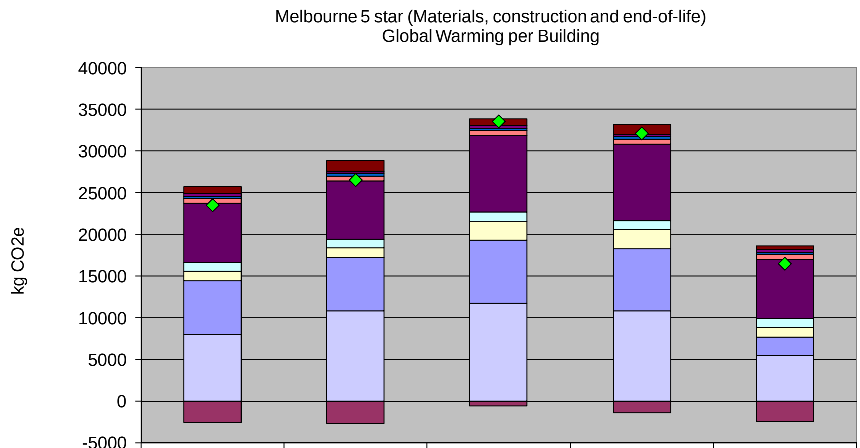


	Global Warming	Photochemical oxidation	Eutrophication	Land use	Water Use	Solid waste	Resource depletion	CED
End of life	-4%	-6%	-3%	-36%	-85%	55%	-1%	-2%
Maintenance	6%	26%	8%	8%	23%	27%	6%	6%
Operation	68%	22%	61%	42%	1%	6%	66%	64%
Materials & constr.	31%	58%	34%	85%	161%	12%	30%	31%

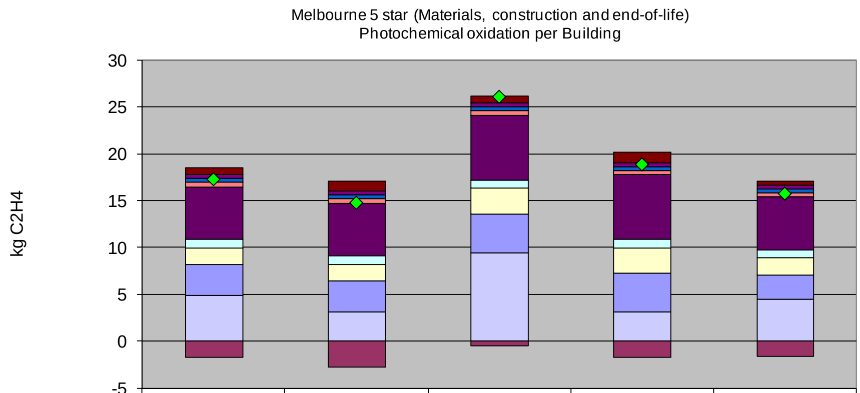
End of life Maintenance Operation Materials & constr.

Appendix H Construction impact drivers

Melbourne

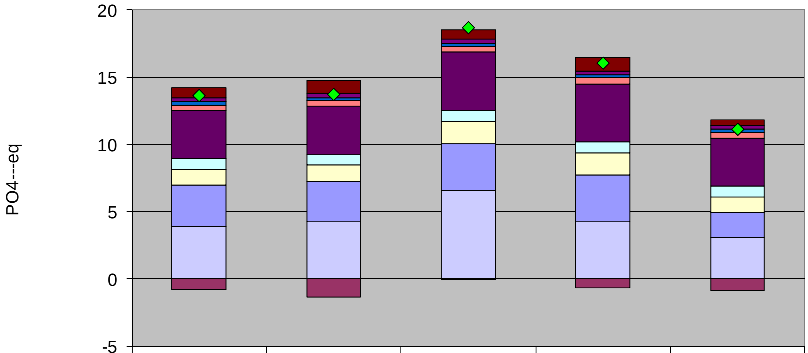


	a	b	c	d	e
Construction	853	1182	824	1163	455
Shading	304	304	304	304	304
Doors	286	286	286	286	286
Windows	577	577	577	577	577
Roof system	7025	7025	9201	9201	7025
Ceiling and ins.	1106	1106	1106	1106	1106
Internal wall system	1127	1127	2273	2273	1127
External wall system	6423	6423	7530	7530	2190
Floor system	8019	10788	11766	10788	5496
End of life	-2591	-2655	-636	-1448	-2426
Total	23494	26528	33596	32145	16441



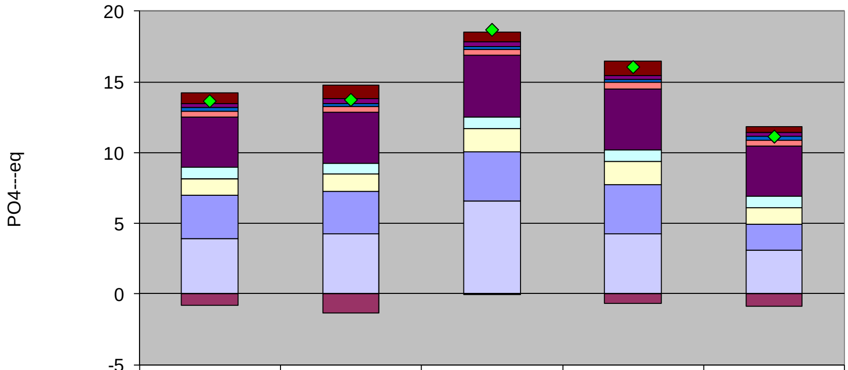
	a	b	c	d	e
Construction	0.81	1.12	0.78	1.10	0.43
Shading	0.42	0.42	0.42	0.42	0.42
Doors	0.42	0.42	0.42	0.42	0.42
Windows	0.45	0.45	0.45	0.45	0.45
Roof system	5.61	5.61	6.92	6.92	5.61
Ceiling and ins.	0.88	0.88	0.88	0.88	0.88
Internal wall system	1.80	1.80	2.72	2.72	1.80
External wall system	3.30	3.30	4.13	4.13	2.56
Floor system	4.86	3.10	9.44	3.10	4.49
End of life	-1.70	-2.77	-0.54	-1.72	-1.69
Total	17.27	14.76	26.05	18.85	15.73

Melbourne 5 star (Materials, construction and end-of-life)
Eutrophication per Building



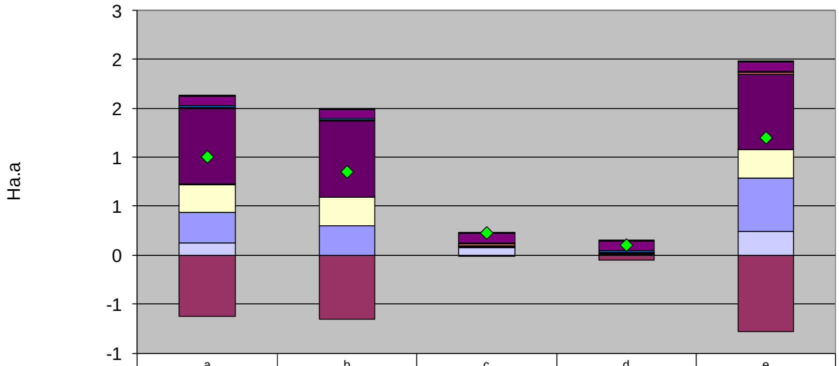
	a	b	c	d	e
Construction	0.71	0.98	0.69	0.97	0.38
Shading	0.32	0.32	0.32	0.32	0.32
Doors	0.22	0.22	0.22	0.22	0.22
Windows	0.42	0.42	0.42	0.42	0.42
Roof system	3.58	3.58	4.35	4.35	3.58
Ceiling and ins.	0.81	0.81	0.81	0.81	0.81
Internal wall system	1.18	1.18	1.65	1.65	1.18
External wall system	3.04	3.04	3.48	3.48	1.81
Floor system	3.93	4.24	6.57	4.24	3.11
End of life	-0.81	-1.31	-0.08	-0.66	-0.89
Total	13.63	13.72	18.66	16.04	11.13

Melbourne 5 star (Materials, construction and end-of-life)
Eutrophication per Building



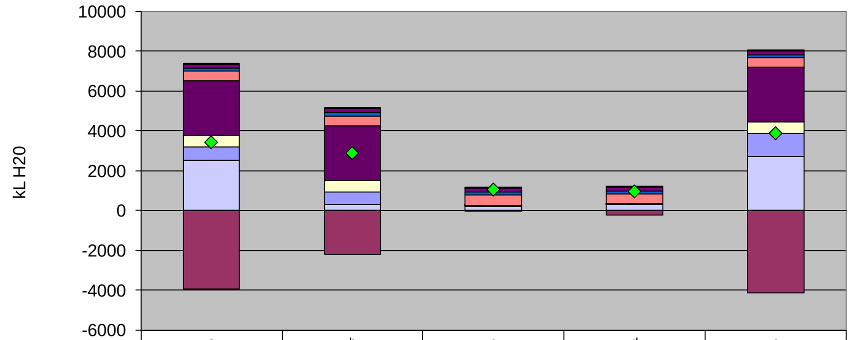
	a	b	c	d	e
Construction	0.71	0.98	0.69	0.97	0.38
Shading	0.32	0.32	0.32	0.32	0.32
Doors	0.22	0.22	0.22	0.22	0.22
Windows	0.42	0.42	0.42	0.42	0.42
Roof system	3.58	3.58	4.35	4.35	3.58
Ceiling and ins.	0.81	0.81	0.81	0.81	0.81
Internal wall system	1.18	1.18	1.65	1.65	1.18
External wall system	3.04	3.04	3.48	3.48	1.81
Floor system	3.93	4.24	6.57	4.24	3.11
End of life	-0.81	-1.31	-0.08	-0.66	-0.89
Total	13.63	13.72	18.66	16.04	11.13

Melbourne 5 star (Materials, construction and end-of-life)
Land use per Building



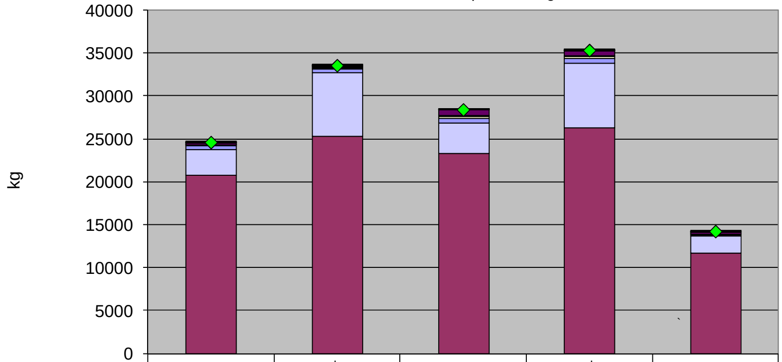
	a	b	c	d	e
Construction	0.00	0.00	0.00	0.00	0.00
Shading	0.10	0.10	0.10	0.10	0.10
Doors	0.01	0.01	0.01	0.01	0.01
Windows	0.01	0.01	0.01	0.01	0.01
Roof system	0.77	0.77	0.00	0.00	0.77
Ceiling and ins.	0.01	0.01	0.01	0.01	0.01
Internal wall system	0.29	0.29	0.01	0.01	0.29
External wall system	0.30	0.30	0.00	0.00	0.54
Floor system	0.13	0.00	0.08	0.00	0.24
End of life	-0.62	-0.65	0.00	-0.04	-0.78
Total	1.00	0.85	0.22	0.10	1.20

Melbourne 5 star (Materials, construction and end-of-life)
Water use per Building



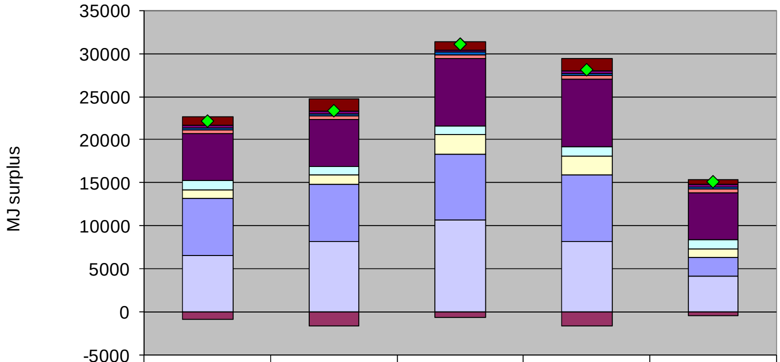
	a	b	c	d	e
Construction	0	0	0	0	0
Shading	196	196	196	196	196
Doors	152	152	152	152	152
Windows	499	499	499	499	499
Roof system	2747	2747	27	27	2747
Ceiling and ins.	2	2	2	2	2
Internal wall system	582	582	4	4	582
External wall system	640	640	29	29	1120
Floor system	2521	271	204	271	2719
End of life	-3930	-2222	-65	-223	-4159
Total	3411	2869	1048	958	3860

Melbourne 5 star (Materials, construction and end-of-life)
Solid waste per Building

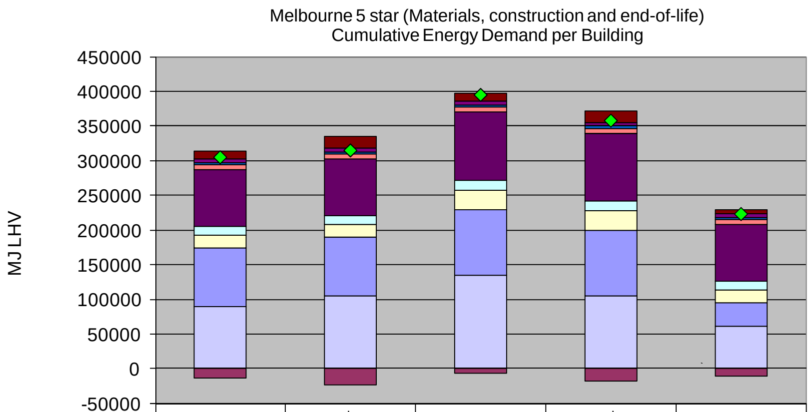


	a	b	c	d	e
Construction	0	0	0	0	0
Shading	31	31	31	31	31
Doors	7	7	7	7	7
Windows	17	17	17	17	17
Roof system	187	187	595	595	187
Ceiling and ins.	93	93	93	93	93
Internal wall system	102	102	276	276	102
External wall system	383	383	554	554	98
Floor system	2963	7444	3546	7444	1949
End of life	20746	25238	23225	26257	11651
Total	24568	33541	28383	35313	14167

Melbourne 5 star (Materials, construction and end-of-life)
Resource depletion per Building

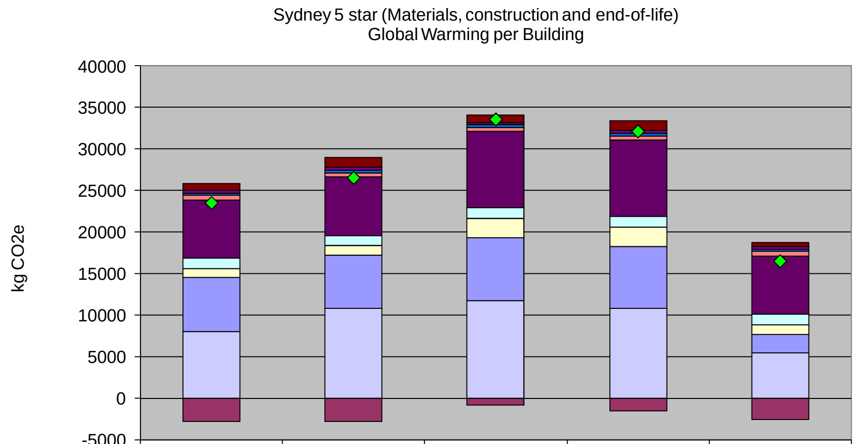


	a	b	c	d	e
Construction	1028	1425	993	1401	549
Shading	280	280	280	280	280
Doors	244	244	244	244	244
Windows	434	434	434	434	434
Roof system	5431	5431	7847	7847	5431
Ceiling and ins.	1039	1039	1039	1039	1039
Internal wall system	1077	1077	2223	2223	1077
External wall system	6549	6549	7659	7659	2100
Floor system	6571	8216	10657	8216	4171
End of life	-852	-1684	-669	-1589	-488
Total	22157	23367	31063	28111	15131



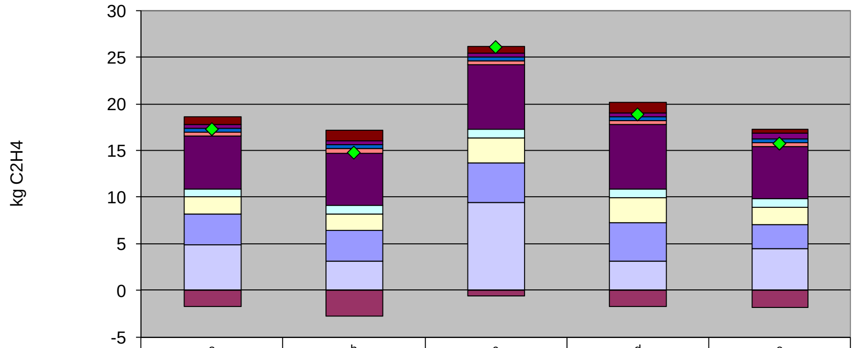
	a	b	c	d	e
Construction	12447	17256	12022	16973	6648
Shading	4867	4867	4867	4867	4867
Doors	3536	3536	3536	3536	3536
Windows	6945	6945	6945	6945	6945
Roof system	81057	81057	98253	98253	81057
Ceiling and ins.	13803	13803	13803	13803	13803
Internal wall system	18108	18108	28562	28562	18108
External wall system	84729	84729	94496	94496	34032
Floor system	88810	104376	134751	104376	60611
End of life	-13880	-24342	-6358	-18288	-10661
Total	304904	314817	395359	358004	222638

Sydney



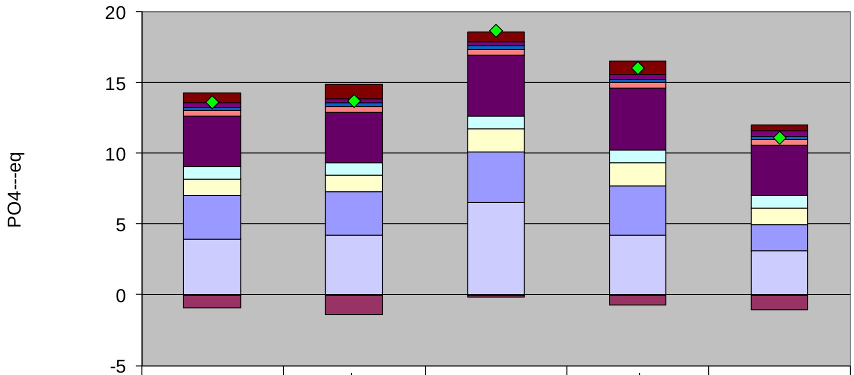
	a	b	c	d	e
Construction	853	1182	824	1163	455
Shading	304	304	304	304	375
Doors	286	286	286	286	286
Windows	535	577	557	577	535
Roof system	7025	7025	9201	9201	7025
Ceiling and ins.	1242	1242	1242	1242	1242
Internal wall system	1127	1127	2273	2273	1127
External wall system	6504	6423	7611	7530	2230
Floor system	8019	10788	11766	10788	5496
End of life	-2766	-2791	-833	-1584	-2631
Total	23494	26528	33596	32145	16441

Sydney 5 star (Materials, construction and end-of-life)
Photochemical oxidation per Building



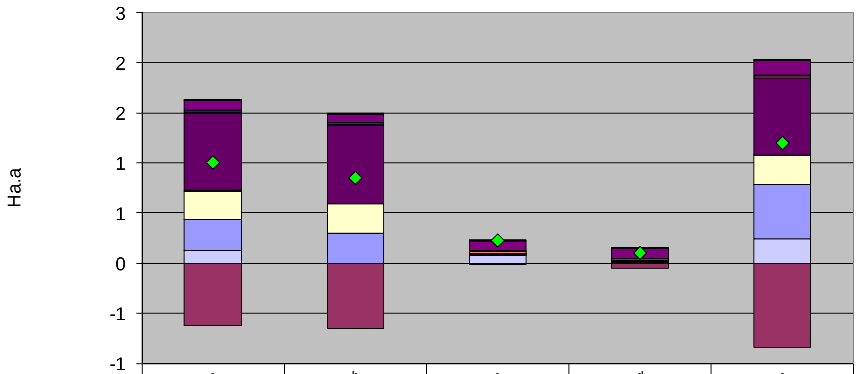
	a	b	c	d	e
Construction	0.81	1.12	0.78	1.10	0.43
Shading	0.42	0.42	0.42	0.42	0.58
Doors	0.42	0.42	0.42	0.42	0.42
Windows	0.44	0.45	0.45	0.45	0.44
Roof system	5.61	5.61	6.92	6.92	5.61
Ceiling and ins.	0.90	0.90	0.90	0.90	0.90
Internal wall system	1.80	1.80	2.72	2.72	1.80
External wall system	3.31	3.30	4.15	4.13	2.57
Floor system	4.86	3.10	9.44	3.10	4.49
End of life	-1.73	-2.79	-0.57	-1.74	-1.87
Total	17.27	14.76	26.05	18.85	15.73

Sydney 5 star (Materials, construction and end-of-life)
Eutrophication per Building



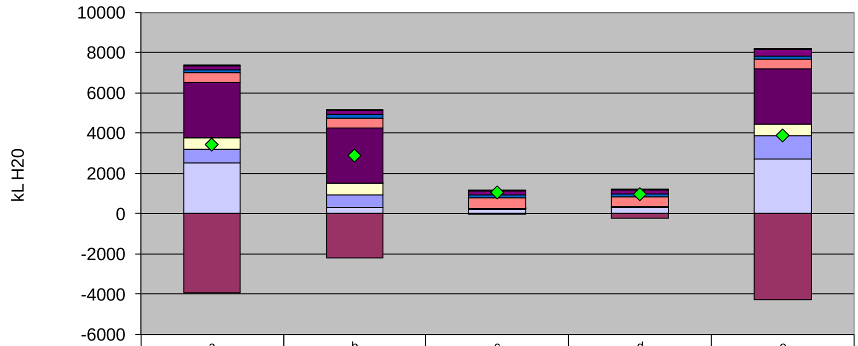
	a	b	c	d	e
Construction	0.71	0.98	0.69	0.97	0.38
Shading	0.32	0.32	0.32	0.32	0.41
Doors	0.22	0.22	0.22	0.22	0.22
Windows	0.40	0.42	0.41	0.42	0.40
Roof system	3.58	3.58	4.35	4.35	3.58
Ceiling and ins.	0.88	0.88	0.88	0.88	0.88
Internal wall system	1.18	1.18	1.65	1.65	1.18
External wall system	3.09	3.04	3.52	3.48	1.83
Floor system	3.93	4.24	6.57	4.24	3.11
End of life	-0.92	-1.39	-0.20	-0.74	-1.08
Total	13.63	13.72	18.66	16.04	11.13

Sydney 5 star (Materials, construction and end-of-life)
Land use per Building



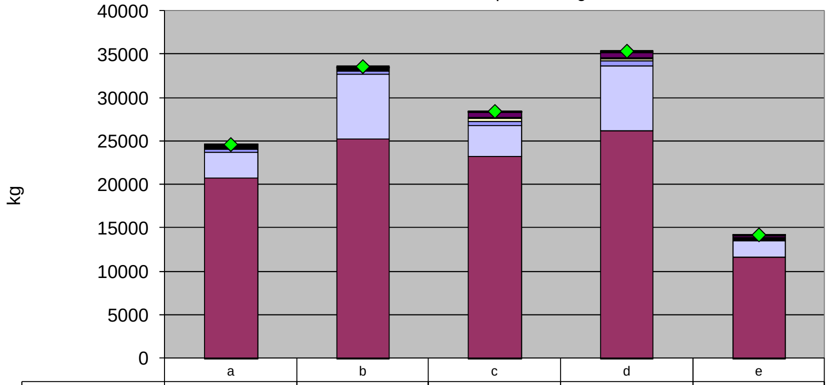
	a	b	c	d	e
Construction	0.00	0.00	0.00	0.00	0.00
Shading	0.10	0.10	0.10	0.10	0.15
Doors	0.01	0.01	0.01	0.01	0.01
Windows	0.01	0.01	0.01	0.01	0.01
Roof system	0.77	0.77	0.00	0.00	0.77
Ceiling and ins.	0.01	0.01	0.01	0.01	0.01
Internal wall system	0.29	0.29	0.01	0.01	0.29
External wall system	0.30	0.30	0.00	0.00	0.54
Floor system	0.13	0.00	0.08	0.00	0.24
End of life	-0.62	-0.65	0.00	-0.04	-0.83
Total	1.00	0.85	0.22	0.10	1.20

Sydney 5 star (Materials, construction and end-of-life)
Water use per Building



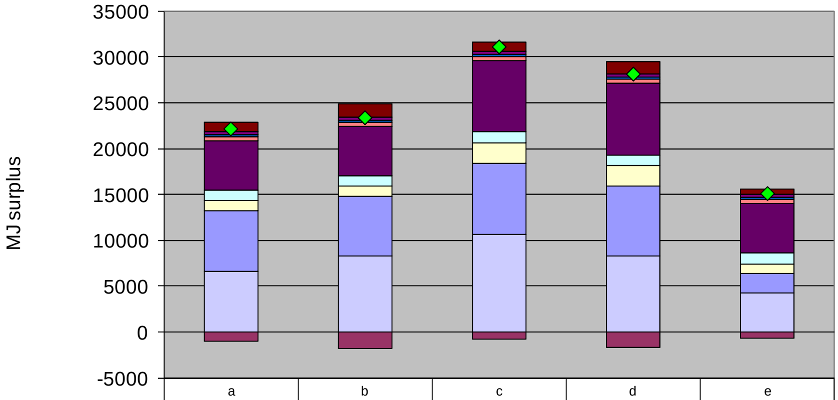
	a	b	c	d	e
Construction	0	0	0	0	0
Shading	196	196	196	196	299
Doors	152	152	152	152	152
Windows	499	499	499	499	499
Roof system	2747	2747	27	27	2747
Ceiling and ins.	3	3	3	3	3
Internal wall system	582	582	4	4	582
External wall system	641	640	29	29	1121
Floor system	2521	271	204	271	2719
End of life	-3931	-2222	-66	-223	-4263
Total	3411	2869	1048	958	3860

Sydney 5 star (Materials, construction and end-of-life)
Solid waste per Building

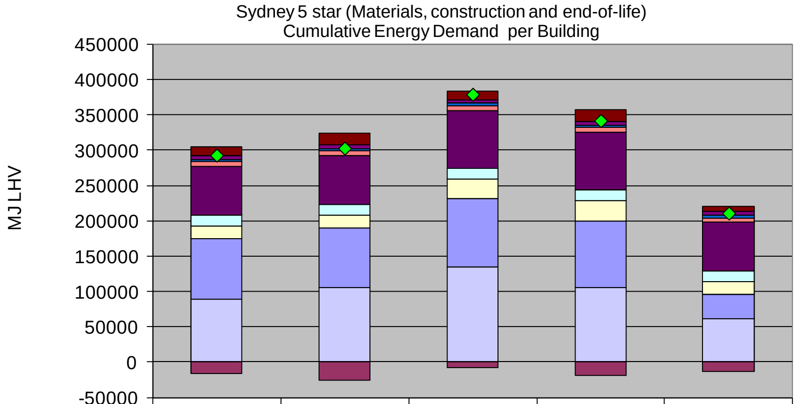


	a	b	c	d	e
Construction	0	0	0	0	0
Shading	31	31	31	31	43
Doors	7	7	7	7	7
Windows	15	17	16	17	15
Roof system	187	187	595	595	187
Ceiling and ins.	98	98	98	98	98
Internal wall system	102	102	276	276	102
External wall system	386	383	557	554	100
Floor system	2963	7444	3546	7444	1949
End of life	20741	25234	23218	26252	11636
Total	24568	33541	28383	35313	14167

Sydney 5 star (Materials, construction and end-of-life)
Resource depletion per Building

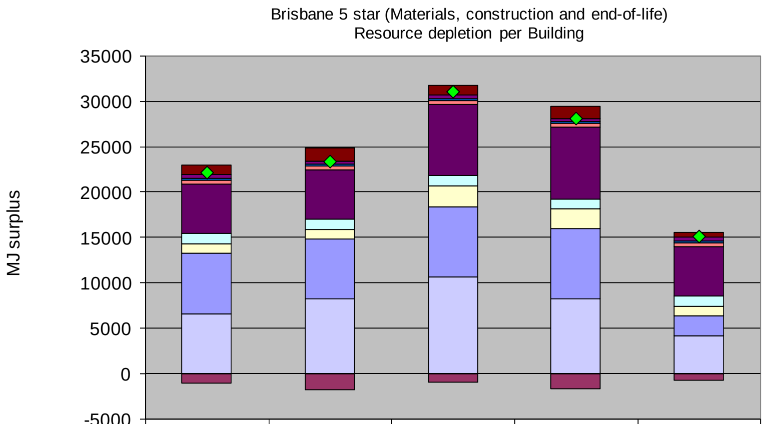


	a	b	c	d	e
Construction	1028	1425	993	1401	549
Shading	280	280	280	280	341
Doors	244	244	244	244	244
Windows	405	434	420	434	405
Roof system	5431	5431	7847	7847	5431
Ceiling and ins.	1158	1158	1158	1158	1158
Internal wall system	1077	1077	2223	2223	1077
External wall system	6620	6549	7730	7659	2136
Floor system	6571	8216	10657	8216	4171
End of life	-1013	-1803	-844	-1707	-674
Total	22157	23367	31063	28111	15131

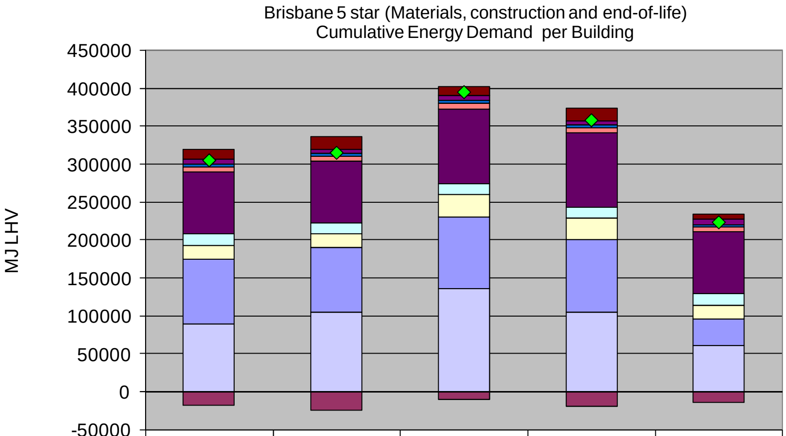


	a	b	c	d	e
Construction	12447	17256	12022	16973	6648
Shading	4867	4867	4867	4867	6338
Doors	3536	3536	3536	3536	3536
Windows	6527	6945	6745	6945	6527
Roof system	68444	68444	81531	81531	68444
Ceiling and ins.	15378	15378	15378	15378	15378
Internal wall system	18108	18108	28562	28562	18108
External wall system	85663	84729	95430	94496	34499
Floor system	88810	104376	134751	104376	60611
End of life	-15971	-25917	-8668	-19863	-13756
Total	292291	302204	378637	341282	210024

Brisbane (other indicators shown in body of report)



	a	b	c	d	e
Construction	1028	1425	993	1401	549
Shading	373	280	373	280	373
Doors	244	244	244	244	244
Windows	405	419	445	419	405
Roof system	5431	5431	7847	7847	5431
Ceiling and ins.	1158	1099	1158	1099	1158
Internal wall system	1077	1077	2223	2223	1077
External wall system	6620	6584	7730	7697	2136
Floor system	6571	8216	10657	8216	4171
End of life	-1106	-1764	-963	-1671	-707
Total	22157	23367	31063	28111	15131



	a	b	c	d	e
Construction	12447	17256	12022	16973	6648
Shading	7123	4867	7123	4867	7123
Doors	3536	3536	3536	3536	3536
Windows	6527	6726	7083	6726	6527
Roof system	81057	81057	98253	98253	81057
Ceiling and ins.	15378	14591	15378	14591	15378
Internal wall system	18108	18108	28562	28562	18108
External wall system	85663	85196	95430	94996	34499
Floor system	88810	104376	134751	104376	60611
End of life	-18227	-25378	-11262	-19357	-14541
Total	304904	314817	395359	358004	222638

Appendix I Sensitivity study - 6 star performance – interventions and characterisation.

Table 50 Energy efficiency measures to achieve 6 star performance.

	Area (m2)	a	b	c	d	e
Melbourne						
Ceiling insulation	201.62	R4	R4	R4	R4	R4
External walls insulation	119.58	R2	R1.5	R2	R1.5	R2
Floor insulation	158.15	R2	no	R2	no	R2
Canvas awning formal,bed2&3 only	12.48	yes	yes	yes	yes	yes
Pergola to north windows	17.10	no	no	no	no	yes
Double glaze kitchen/dining/family only (3/6/4low e)	11.39	yes	yes	yes	yes	yes
Double glaze formal only (3/6/4low e)	9.32	no	yes	no	yes	yes
Sydney						
Ceiling insulation	201.62	R6	R4	R6	R4	R6
External walls insulation	119.58	R2.0	R2	R2.0	R2	R2.0
Floor insulation	158.15	no	no	no	no	no
Canvas awning formal,bed2&3 only	12.48	yes	yes	yes	yes	yes
Pergola to north windows	17.10	yes	yes	yes	yes	yes
Pergola to formal only	9.00	yes	no	yes	no	yes
Pergola to bed 2, bed 3 only	4.80	yes	no	yes	no	yes
Solar glass (low e) formal,bed2,bed3 only	12.48	no	yes	no	yes	no
Solar glass (low e) kitchen/dining/family only	11.39	no	yes	no	yes	no
Double glaze all (3/6/4low e)	32.97	yes	no	no	no	yes
Brisbane						
Ceiling insulation	201.62	R6	R6	R6	R6	R6
External walls insulation	119.58	R2.0	R2	R2.0	R2	R3
Canvas awning formal,bed2&3 only	12.48	yes	yes	yes	yes	yes
Pergola to north windows	17.10	yes	yes	yes	yes	yes
Pergola to formal only	9.00	yes	no	yes	no	yes
Pergola to bed 2, bed 3 only	4.80	yes	no	yes	no	yes
Solar glass (low e) to formal,bed2,bed3 only	12.48	no	yes	no	yes	no
Solar glass (low e) kitchen/dining/family only	11.39	no	no	no	no	no
Double glaze (3/6/4low e) all	32.97	yes	yes	yes	yes	no
Double glaze (high eff, 3/12a/4low e) all	32.97	no	no	no	no	yes
Double glaze (high eff, 3/12a/4low e) kitchen/dining/family only	11.39	yes	no	yes	no	no
Double glaze (high eff, 3/12a/4low e) formal only	5.52	yes	yes	yes	yes	no
Double glaze (high eff, 3/12a/4low e) bed2, bed 3 only	6.96	yes	yes	yes	yes	no

Accross the board assumptions (unless stated otherwise):

Glass: 6.38mm lam in single glaze
Reflective sarking to roof and walls
Weatherstrips to all windows and doors
Internal wall to kitchen and laundry match external wall insulation level.

Table 51 Characterisation - 6 star performance.

Melbourne	unit	a	b	c	d	e
Global Warming	kg CO2e	10.5	10.5	11.5	11.2	9.7
Photochemical oxidation	kg C2H4	0.004	0.004	0.005	0.004	0.004
Eutrophication	kg PO4--- eq	0.008	0.009	0.009	0.009	0.008
Land use	Ha a	2.14E-04	1.97E-04	1.17E-04	1.09E-04	2.35E-04
Water Use	KL H2O	0.418	0.360	0.143	0.142	0.493
Solid waste	kg	3.1	3.9	3.5	4.1	2.1
Resource depletion	MJ Surplus	11.389	12.050	12.315	12.576	11.050
Cumulative Energy Demand	MJ LHV	144.7	149.1	153.9	153.9	139.3
Sydney						
Global Warming	kg CO2e	5.5	5.8	6.6	6.4	4.8
Photochemical oxidation	kg C2H4	0.003	0.003	0.004	0.003	0.003
Eutrophication	kg PO4--- eq	0.003	0.003	0.004	0.004	0.003
Land use	Ha a	2.18E-04	2.03E-04	1.27E-04	1.14E-04	2.39E-04
Water Use	KL H2O	0.425	0.371	0.162	0.153	0.502
Solid waste	kg	3.0	3.9	3.4	4.1	2.1
Resource depletion	MJ Surplus	5.139	5.279	6.075	5.806	4.492
Cumulative Energy Demand	MJ LHV	69.7	70.6	79.0	75.4	62.2
Brisbane						
Global Warming	kg CO2e	6.2	6.3	7.2	7.0	5.6
Photochemical oxidation	kg C2H4	0.003	0.003	0.004	0.003	0.003
Eutrophication	kg PO4--- eq	0.003	0.003	0.004	0.003	0.003
Land use	Ha a	2.17E-04	2.03E-04	1.26E-04	1.14E-04	2.38E-04
Water Use	KL H2O	0.391	0.365	0.128	0.147	0.456
Solid waste	kg	3.1	4.0	3.5	4.2	2.1
Resource depletion	MJ Surplus	5.300	5.166	6.236	5.693	4.685
Cumulative Energy Demand	MJ LHV	73.7	72.2	83.1	76.9	66.8

Appendix J Peer review panel comments and actions

Peer review was undertaken in two stages and incorporating two basic functions as shown in Table 52. The review was undertaken in this fashion to facilitate external comment during project development in the early stages as well as at study completion. Reviewers involved were chosen to cover a range of capabilities and representing, where possible, parties likely to be affected by the study. An LCA expert was also selected to review the technical aspects of the study.

Comments received through this process have been documented in Table 53 and Table 54 below. Wherever possible, comments were addressed within the body of the report. A challenge throughout the exercise involved addressing comments while at the same time attempting to manage scope expansion. It is acknowledged by the author that the study could be legitimately expanded in a number of directions, however these were not possible within the project timeline and budget. Hopefully future studies will pick-up some of these opportunities.

Issues noted after issue of the peer-reviewed report

Following the issue of the peer reviewed report, a number of minor technical changes were made based on feedback from a range of predominantly industry based sources. These changes are noted in Table 55.

Table 52 Dimensions of peer review completed

	Goal and Scope	Final Report
Panel of interested parties	Review completed	Review completed
Independent expert LCA reviewer	Review completed	Review completed

Table 53 Peer comments from Goal and Scope Review

Section	Reviewer Comment	Author Action
Scope	Should we be considering 6 star given ABCB current intentions?	Yes. Included in study.
Scope	Timber on slab to steel on suspended floor is not apples with apples: Need to add: Steel on slab Steel with light-weight cladding	Agree. Have added steel frame on slab only. Steel with light weight cladding not assessed, but difference could be inferred by considering elevated floor designs using brick veneer.
Scope	Two storey archetypes should also be included. Material mix and relative benefits will change when you go to two storey	Would like to do, but outside scope and budget.
Funct unit	“per square metre of conditioned area” is the whole house conditioned and does AccuRate model the entire house?	No. Whole house is not conditioned. Garage and laundry not conditioned. Functional unit statement altered to refer to “internal floor area”.
Functional unit	Given the same basic design for the archetypes to be considered, the functional unit “1 m^2a” is all right.	OK
Boundary	Should you not be factoring in the other appliances that generate heat and the cooling loads required to do something about this?	Some studies do this, some do not. It has been decided to exclude other appliances as their impacts are not directly connected to the construction of the building in the same way that HVAC is. Lighting is not considered connected to building construction, and is related more to building design (window location). Prior studies have also shown lighting impacts to be minimal over lifecycle relative to HVAC. Provision of hot water and refrigeration are also believed to be related to appliance design rather than building construction.
Boundary	Because *Potable* water supply is included in Figure 3.1, one might think that not all water use is included. From an LCA practitioner point of	Potable water supply has been excluded from the study. This has been clarified in system boundary diagram and associated discussion.

Section	Reviewer Comment	Author Action
	view I assume "Resource extraction processes" covers all water use.	
Boundary	Apart from Material recycling and disposal to landfill, incineration with energy recovery might be included (wood components). At least in the Dutch context it would be important.	Unfortunately, disposal to energy recovery is not common in Australia.
Boundary	Is only timber from agricultural processes taken into account? And therefore no timber that originates from primeval forest?	Timber from pine plantation and native forest is included. The hardwood inventory used assumes native forest harvest, however the definition of 'primeval' is a problematic one given settler intervention over the past 200 years. Inventory is silent on the issue.
Boundary	I understand the disregard of carbon that is "part of natural carbon cycles" next to the "attempt that will be made to trace biogenic carbon". In the upcoming report it should be clear when carbon is included and when not. Does the natural carbon cycle include extraction from primeval forest?	Carbon cycles are directly addressed in the report. Sequestration of carbon is addressed as an end-of-life process. Carbon balance impacts due to extraction from primeval forest is not addressed by the timber inventory.
Boundary	Construction impacts should be included.	Included. More work could be done in this area to better estimate.
Impact assessment	Not being familiar with the BPIC midpoints: is "Resource depletion" (only) abiotic depletion? Table 3 refers to Ecoindicator 99 and (indeed) mineral and fossil resources.	Yes. Fossil fuels and minerals.
Impact assessment	Table 3: For Global Warming I would use the latest IPCC factors (e.g. 23 for methane instead of 21).	We have settled on the Kyoto factors as we are still using these in the bulk of greenhouse gas reporting locally. Dept of Climate Change still uses these factors and they recommended in the Best Practice Guide to LCIA by Grant and Peters. This also keeps the carbon results (a focus for many) consistent with other local data sources.
Impact assessment	Since reference is made to both CML 2000 and Ecoindicator 1999, it might be good to include reference to the development of a kind of hybrid: ReCiPe (http://www.lcia-recipe.net). The actual use of this recently published method is probably not feasible.	Agree. I would expect Recipe would provide a more contemporary impact assessment method for the study. We have used IMPACT 2002+ because it seems to be the basis for the newly developed BPIC method in work.
Impact assessment	Solid waste mentioned but not included. Waste should be included (volume and mass).	Included.
Transparency	Can we see the house plan(s), and also, which micro climate and orientations will be used?	Yes. Plan is included in report and orientation is noted.
Transparency	Include 1 page with information / plan of the Standard Single Storey House (since your audience is broad).	Plan added.
Data quality	Data likely to be of varying quality. Data assessment needs to do more than just observe quality differences. May need to broaden sensitivity analysis.	Data quality issues have been assessed using sensitivity where they may affect directional conclusions. End-of-life assumptions in particular.
Data quality	Can more updated data be found for steel?	Steel inventory data selected based on relevance and timeliness. Data compared to alternative sources and found be conservative for most indicators.
General	Shading is generally a cheaper method of improving thermal performance than glazing.	Agree. Have prioritised shading devices to improve performance ahead of glazing.
General	Include a list of abbreviations (BPIC, HIA, etc.). Like with FWPA (under 1 Introduction) include some explanation too (since your audience is broad). Does this association cover all wood construction industry?	Abbreviations definitions have been added in text, sequentially. FWPA represents most timber product manufacturers in Australia.
General	Is CSIRO directly involved in research or reporting. Or reviewing?	No. They have provided the timber inventory only.

Table 54 Peer comments from Final report review meeting and LCA expert

Section	Reviewer Comment	Author Action
2	"A few comments the on the draft report text: - Buildings don't consume, people in the building sectors consume - A lot of the construction sector commodity flows are the result of construction of non-building infrastructure (eg., roads, bridges etc) - as does the solid waste generation. - It's commodities – not raw materials. - The reports only apply to OECD countries – it's not a global estimate. - Waste generation and disposal to landfill (landfill waste) are two different things. The majority of C&D waste generated (the figure cited in the OECD reports) is actually recycled – not landfilled." "- One of the objectives of the study is to incorporate the impacts of building materials so it seems funny to include a statement at the beginning that actually excludes these impacts, without actually stating that - These reports appear to be based on data from the early 1990s which is now almost 20 years old. A lot has changed since then!" *Author truncated comment to fit table*	Suggested changes to wording adopted.
3 table 1	It is misleading to headline this aspect as performance. The star ratings only apply to a small proportion of a buildings performance (ie. thermal comfort or heating and cooling demands). The more accurate title is " building envelope thermal performance"	Table titled changed to "Heating and cooling performance" and references in text adjusted to be more specific. Eg Performance reference under table 2 deleted and replaced by 'potential environmental impacts'.
3	Don't you mean that you made adjustments which were achieved using methods that minimise materials use? Or were the most practical or easiest? The embodied impacts (not just energy) were then examined.	No. A deliberate attempt to select interventions that minimised incremental embodied was undertaken. Although a rigorous analysis was not undertaken, a number of interventions were trialled for each construction type and those contributing the least to CED were selected. This was process did not just consider material mass, but also the energy intensity of the materials involved.
4 "Lippke reports an increase in life cycle impacts for the Minneapolis house of 9%..."	It reads as though as though substituting wood for steel results in an increase in life cycle impacts when the studies actually show a decrease. Also not sure if it's just GWP referred to here or all impacts Also – the substitution only applied to the wall and roof frame (not the floor)	Agree wording is inaccurate. Reworded to properly reflect direction of differences.
4	Roof structures described within table should describe steel roof as 'steeldeck'	Table updated.
4	Climate zone for Sydney described in table should refer to Eastern Sydney	Table updated.
5	A one sentence introduction above Figure 1 (construction) and 2 (life cycle, including operation) improves readability.	Added.
5.2 System boundary	- Needs an extra box above "resource extraction process" as timber has a process before that step "Establishment and Growth" as impacts from these processes have been included (eg. water use, carbon sequestration, land use) - At the other end – needs an extra box below" Landfill processes" (e.g. carbon) - It's not clear if recycling processes are included in the system boundary Basic outdoor structures are, or should be included under building elements (ie., shade pergola, deck, landings)	Agree there is scope to add more detail to the system boundary chart, however I have tried to keep unit processes generic. If I start adding unit processes that are unique to a material, I will need to do so across all materials considered. To address the comment I have adjusted the unit process to read "Resource extraction and/or forestry processes". Building elements are updated to incorporate shading elements (other elements are excluded). Recycling has not been altered. Again, there is scope to add detail (ie collection, sorting, reprocessing) but I have tried to keep the diagram relatively simple.
5.2.1 Products derived from agricultural	- The majority of timber is derived from processes quite distinct from agricultural processes – as recognised by the ANZSIC industry codes.	Wording adjusted to explicitly include forestry.

Section	Reviewer Comment	Author Action
processes	- The correct term would be "Products derived from agricultural and forestry processes. - The term sequestration is used when sequestration and storage are	
5.3	- The study makes assumptions regarding the fate of carbon stored in timber in landfill – not "regarding the deposition of carbon in landfill". - In this study a portion of carbon stored in timber is assumed to be sequestered in landfill in the long-term (i.e. over at least 100 years not indefinitely) - Storage of carbon in timber in landfill is the subject of the sensitivity study	Carbon storage used to in place of sequestration where appropriate.
5.6 Table 5	- Coarse spelt incorrectly in Water Use - I like the highlighting of the solid waste and CED indicators and the footnote. - Similarly The Water use and Land use indicators should be highlighted in a different colour and a footnote added such as "Water and land use represent the most primitive of the impact assessment methods. They are included as a broad indication of environmental impact that require deeper investigation to fully confirm. Careful interpretation of both these indicators is particularly important"	Corrected spelling. There is potential for a range of colour coding in the indicators. Shading has been used to highlight the core differences in indicators used. Other indicator limitations are handled within the text.
5.6.1 Fig 4	This BPIC diagram has been updated since this one. Should include the latest version. I will provide	Not available at time of report printing.
5, page 10, last para.	ot→to	Amended.
6.1	Include double garage in functional unit definition.	Statement altered to include 'double' garage.
6.1	"part of which is climate controlled" is not very precise. Looking back: can you add a range or percentage?	Added exact percentage and rationale in footnote.
6.2.1, 8.2.1	'Carbon stored ... in ... the structure of a building' is a carbon 'credit' assessed. According to 8.2.1 "The inventory used does not include carbon sequestered in wood products during the use phase of timber product life. The assumption applied here is that the construction types considered are not incremental additions to the building stock, but are replacing existing buildings in a steady state population (this assumption is tested as a sensitivity under Section 11.3)." At first reading this seems contrary.	Section reworded. Carbon stored in structure is not included as a 'credit' in the study. The only sequestration considered is related to timber in landfill.
6.3 & 8.6	Increase of materials in the economy (storage) is neglected.	Agree.
6.6	"Cumulative energy demand (embodied energy) has also been included as it represents a pre-cursor to environmental impacts". Double counting is avoided can be included more explicitly.	Section discussing impact assessment method has been rewritten to make more precise and to highlight precursor indicators.
6.6 Table 5	Distinguish clearly (e.g. thick line) between real impact categories, the LCI categories Land use and Water use, and the 'recognisable indicator Cumulative energy demand' (which is like stated previously in 6.6 no real impact assessment indicator). Why is 'Solid waste' not included here. Result tables like table 9 presents 'Solid waste'. What is the definition of 'Solid waste'? Waste land filled?	As above.
6.6.1 & 11.4	Weighting is outside ISO 14040/44 standard.	Agree. Added sentence stating this.
7.1 Material quantities	To assist understanding, the total area of house needs to be included here (square metres)	Areas included in Table 7 of this section.
7.1 Table 6	Subfloor height is too high on elevated floor houses – needs to be 0.4m (0.4 plus 0.2 for joists etc). Windows should be aluminium in all except the weatherboard house	Agree to reduce subfloor height. 0.8m reduced to 0.6m, and enclosure changed from insulated fibre cement to insulated weatherboard. Other changes suggested have not been incorporated.

Section	Reviewer Comment	Author Action
	Glass thickness seems to be too thick. I thought 3mm was standard for windows? Subfloor on weatherboard elevated floor should be enclosed with weatherboard – not fibre cement. Standard floor coverings should be included. (ie. tiles, carpet and underlay and solid timber floors) Type timber used in weatherboard (softwood/hardwood) is not nominated Concrete slab is too thin. Wafflepods are not standard throughout Australia. Interior doors are usually MDF and plywood or solid wood - not particleboard. - Why is landings and deck/paved area excluded? These would be standard inclusions - Suggest including paved courtyard and concrete landing in slab on ground and timber options for elevated floors Timber used on deck and landing (KD hardwood boards and green hardwood substructure)	
7.1 Table 7	It is very odd that deck and landing are excluded.	The functional unit was defined around the building and not structures external to the envelope.
7.1 Table 8	- Minimise hardwood in b, c and d - Why is less softwood framing needed in house e? - 1.4 m3 of weatherboard in house e seems too low – particularly if it is extended to cover the subfloor area - Why is there 172 kg of framing steel used in house e? - Why is there 40kg of structural steel used in house e? - Roofing material for the garage should be the same as main house. - Concrete used in houses b and d is underestimated. Should not be wafflepod construction - Subfloor height of 0.6m will reduce mortar and brick quantities in house a and c - Need to add a solid timber floor covering and contrast with carpet and floor tiles on slab on ground - Reduce fibre cement sheeting with coverage of timber to cover whole sub-floor perimeter.	Corrected error in softwood timber quantity in house e. Recalculated weatherboard quantities – increased to 2.8m3. Steel not required in house e. Steel beam to garage replaced with hardwood. Garage roofing is different due to flat roof design. Concrete quantities checked using alternative methods and sources (refer Appendix D). Floor coverings excluded. Floor surround for house e changed to insulated weatherboard.
7.3.1 text and in Table 9 caption	- The timber data is not in the AusLCI inventory as it says here. At this stage it belongs to FWPA and is not in the BPIC inventory database either so it is more correct to say FWPA LCI inventory. (Note it is called the Timber LCI in a later section). - Need to include impacts for kiln dried softwood, kiln dried hardwood and green hardwood here Note: need to note here that solid waste and cumulative energy demand (or CED as it should be referred to in this and all the other tables) are only <u>precursors</u> to impact.	Updated section to highlight LCI has not been released. Have reverted to CED throughout report. Green timber products not used in the study.
7.3.2 Table 10	Impacts for steel should be related to per tonne so the units are the same as the other materials	The section is not intended to provide material comparison per tonne. In fact this has been avoided throughout the study as it encourages conclusions to be drawn that do not consider performance.
7.3.5	Should include aluminium in a separate table as aluminium windows need to be included in houses a - d	Timber windows retained.
7.3.5	- The inventory includes water use during the production phase but doesn't include the carbon stored during the production phase. - Note: carbon is not <u>sequestered</u> during the use phase - it is <u>stored</u> (in the timber). - The assumption applied that the construction is not additional is not correct. We are talking here	The study has not attempted to address this issue, it simply assumes that there is no 'credit' associated with carbon storage in building stock.

Section	Reviewer Comment	Author Action
	about new housing on Greenfield sites – not replacement of existing housing stock.	
7.6	- Exterior painting interval should be 15 years - If painted as recommended external timber cladding (and hardwood windows) will last 100 years - Why is interior painting included here?	Already debated by reference group. Assumptions made are intended to be conservative estimates. Agree that further work could be undertaken in this area, however it did not surface as a key driver of study outcomes.
7.7	- The reference cited (Crowther 2000) cites recycling rates for residential which appear to be equal quality, if not better, than those cited for commercial. - As this is a residential housing study it would appear more appropriate to use the residential reuse/recycling data. - E.g. Timber rate was 79% reused/recycled.	Commercial recycling data used due to its completeness. Anecdotal feedback from reviewers has been that recycling rates should be lower than those assumed, in general. Agree that this is a point of contention and have used sensitivity analysis to assess significance.
7.7.1	The first statement is too definitive. There a lot of variables and assumptions here .	Deleted statement.
8.1	Request that lifetime be stated explicitly	Added section on building life.
8.1	Table does not address weatherboard correctly	Weatherboard exterior wall system. Also added steeldeck roof system.
8.1	Functional area of building should be highlighted in table of areas. Area excluding garage is confusing so should be removed.	Both items actioned in report.
8.2.1	Is 'steady state' appropriate for hard wood too?	Yes. No incremental addition to carbon stock in buildings is included in the study.
8.2.1	The timber data isn't really unique, and in actual fact, hasn't technically been provided to AusLCI… only brick and (I think) plasterboard has at this stage.	Sentence stating 'unique' removed.
8.2.1	What does the last paragraph here practically mean?	Intended to signal that there is no carbon credit being allocated to timber products because they store carbon in building stock. Some other studies do this. Have reworded paragraph to help convey this.
8.2.2	Steel data table missing.	Added.
8.2.4	Brick LCA released that should be used to update global warming emissions from brick production.	Global warming figure updated using shift in fuel mix and reduction in fugitive CO2. Matches Rouwette (2010).
8.3	On site construction impact estimate method does not make sense. Transport distances would be a better approach.	Agree. Have based around transport, and used Cole as sense check.
8.4	How was the embodied energy of the design alterations (ie solar glass) factored in?	Low e film is assumed to be incorporated into the glass. A problem with the inventory did not pick this up. It is now counted and included in the impact assessment.
8.5	Disagree that timber cladding will last 100 years. 50 years more appropriate	Some debate about this. Many examples of properly maintained timber buildings that last 100 years. Not sure study is sensitive to this assumption in any event so have reduced to 50 years to be conservative.
8.6	General consensus that few materials are actually recycled from building sites. Believe table represents 'overly optimistic' view.	Not much data available regarding the proportion of material recycled when a building is demolished. Have included optimistic view to ensure high intensity materials are not overly penalised (steel, aluminium). Is also based on a published study. Certainly agree there is scope to improve understanding in this area.
8.6	Since metals are traded globally for aluminium the world input ratio for primary/secondary production might be an alternative to include in a sensitivity analysis. For steel that is the BOF/EAF ratio. Regardless the specific application. Thus substitution could prevent the production with the same ratio, taken into account 'stock formation' in the build environment.	Agree. Added sensitivity to assess steel recycling that generates avoided steel product equivalent to the impacts of BOF and EAF steel produced at the world BOF/EAF production ratio irrespective of original production source (EAF or BOF).
9.1	Some introduction before table 19 would improve readability.	Added.
9.1	I am assuming this will be re-done with the new brick figure from table 12?	Global warming figure updated using shift in fuel mix and reduction in fugitive CO2. Matches Rouwette (2010).
Fig 14	These figures are somewhat different to other recent LCA work undertaken: could be a modeling software issue, but in general, DTS 5	Agree. Error in interpretation of Accurate energy data. Prior report used load per unit of conditioned area and applied it to the total area of the house.

Section	Reviewer Comment	Author Action
	Star seem to be more efficient.	This has been corrected, by adjusting the load per conditioned area to a load per functional area. This reduces energy consumption. Refer Appendix E.
	What is the difference between tables 21 & 22?	Poor wording above table 22. Table 21 refers to entre construction type, whereas table 22 refers to floor subsystems only.
10.3	The various scenarios are very confusing	Unfortunately there were a lot of parameters to test. This area is probably worthy of study in isolation.
10.3.3	Dilution issues: this was a considerable factor in the Think Brick work and I think it needs more discussion: ie x% difference in a material that only contributed x% of total global warming impacts etc.	Added some extra discussion. Shows how large differences in embodied impacts do not necessarily translate to large differences in lifecycle impacts.
10.4	I am assuming that this is excluding operational impacts whereas 10.3.1 (etc) was including operational impacts	Yes. Excludes operational impacts. Have updated title to clarify.
Fig 19	As per table 15, construction A, C & E had solar glass, yet it doesn't appear to be reflected here Similar to this, I would have expected A & C, B & E to have had the same values for the external walls and floor: why isn't this the case?	Problem with solar glass inventory has been corrected – it is now included properly. Other small differences due to insulation differences, or frame material differences.
10.4 2nd para	Concern that comparison drawn between type a and type e is not fair because most brick veneer homes built with concrete slab floor.	Agree, that elevated floors within brick veneer homes are not common anymore. The comparison is drawn this way to isolate the distortion that the concrete slab floor would have versus an elevated floor. By comparing two elevated floor construction types, it is easier to see the impact of the cladding system. Although not explicitly done in the report, it is possible to compare all of the construction types in the report as they are functionally equivalent. Some of this comparison has been left to the reader to undertake, but is nevertheless worthwhile.
11.2	Page 55: "maintained of they can be demolished" of→or	Amended.
11.3	Does table 30 only concern timber or all materials?	All materials, however timber is primary focus for carbon in landfill scenarios. Updated wording to clarify.
11.4	Reference missing	Corrected.
11.4	Do not agree with comment that IMPACT 2002+ results are directionally consistent with global warming	Added global warming on second axis.
11.4	I am not sure that the results between fig 30 and 13 are directionally consistent… but hard to tell	Added global warming on second axis.
12	As per 10.4 above	Refer 10.4 above.
12	A reference to either 9.2, figure 10/11 or appendix F/table 47 improves readability on normalisation.	Added chart to conclusion.
General	Ensure report language consistently refers to construction types and not design types or materials.	Updated.
General	Should add all locations to appendix G.	Added
General	It seems that the comparison is geared toward flooring systems (ie elevated v slab on ground), and secondarily, framing systems (timber v steel). To this end, during the introduction, goal etc, I think more explicit reference to these comparisons would be useful for the reader to prevent them making more general conclusions.	The goal of the study is comparison. Comparative assessments tabulated are based on areas of likely interest to readers, however broader conclusions could be drawn. Intent was to do the obvious 'math' in the report, but this does not preclude other comparisons. Effort has been made to assess each construction type in a consistent fashion, so this should be possible.
General	Higher embodied energy v higher energy efficiency. There seems to be an implicit assumption in this work that this cannot be the case (ie "adjustments necessary to achieve 5-star performance are achieved using methods that minimise associated incremental embodied energy").	All statement is supposed to reflect is that interventions needed to achieve 5 or 6 star have been done so in an environmentally efficient manner. Agree that higher embodied impacts can be offset by higher efficiency.
General	Design interventions: Some of the design interventions are potentially quite expensive (ie solar glass and double glazing) and there is a clear trend that the houses with elevated	Section 8.5 lists interventions incorporated for 5 star and appendix I lists interventions for 6 star.

Section	Reviewer Comment	Author Action
	flooring need more design interventions than those with slab on ground, or put another way, the lower embodied energy houses need more design interventions than the higher embodied energy houses. To this end, I also think explicitly stating what the design interventions are (for both 5 & 6 star) would be useful.	
General	Life Cycle Impacts: Section 10.2 discusses the significance of construction and materials ("… [they] play a major, and potentially increasing role in determining the lifecycle impacts of the buildings considered"). This section seems to imply/could be interpreted that as higher star ratings are mandated, embodied energy will have to be lower because it will represent a larger proportion of the life cycle impacts	The section is intended to highlight that as buildings become more efficient, their embodied impacts will become more significant parts of the total life cycle impact.
General	The move from 5-6 star (sensitivity analysis): Table 29 is particularly misleading because it implies that a move from 5 to 6 stars increases the global warming impact gap between brick and weatherboard (in favour of weatherboard), yet the design interventions for these houses include greater insulation, additional pergolas, and double glazing which weren't used on the slab on ground houses.	6 star performance may mean that light weight designs like the weatherboard need more insulation, however the incremental embodied impacts of this insulation tend to be more than offset by the increase in efficiency that 6 star requires, hence the gap widens.
General	Note that Maddox et al used 1st generation thermal modeling software which has now been demonstrated to be very inaccurate	Yes agree. A good piece of work, but a lot has changed since then.
Appendix I	There appears to be some redundancy in design Interventions	Agree. Significant trial and error analysis was undertaken to come up with the interventions shown.
General	Author action	CSIRO issued updated figures for sawn hardwood and sawn softwood.
General	Author action	Error corrected in recycling treatment of timber products (not assessed completely in original report).

Table 55 Comments and actions following issue of the peer-reviewed report. Comments in general have come within FWPA or associated organisations.

Section	Reviewer Comment	Author Action
Table 22	Concrete impact has negative land use.	The error is caused by the modelling of concrete recycling which used an avoided product of gravel. The impacts of gravel production avoided were inconsistent with those used for gravel in concrete production. This was corrected to ensure gravel impacts were consistent in concrete production and reprocessing. Implications for results: The change resulted in: a change in the characterisation of less than 1% for global warming, photochemical oxidation, eutrophication, resource depletion and cumulative energy demand; a 1-3% reduction in water use, and a 9-13% reduction in solid waste. Change was most significant in houses incorporating a higher proportion of concrete, however study conclusions were not directionally affected. The Authors opinion is that the change does not materially affect study outcomes.
Section 8 (results in general)	Conversion of carbon content to methane is incorrect in timber in landfill models.	Determines carbon content then multiplies by molar mass of 18 – should be 16. Overstatement of methane emissions from timber in landfill. Value has been corrected, and entire model recalculated. The change resulted in a less than 1% change to any indicator in the characterisation.
Section 8 (results in general)	Water normalisation figure incorrect	The water normalisation figure used to create the normalised results shown in Figures 11,12,33 and Appendix F was a per capita consumption of 4.4kL. this is in error and has been replaced with a corrected figure of 0.9kL per capita. This change increases the relative significance of water in the normalised results chart.

Section	Reviewer Comment	Author Action
		As normalisation is not central to conclusions, the change only affects the charts noted.
Section 8 (results in general)	Resource depletion normalisation figure incorrect	The water normalisation figure used to create the normalised results shown in Figures 11,12,33 and Appendix F was 2.4 GJ surplus per capita resource depletion. This is in error and has been replaced with a corrected figure of 53GJ surplus per capita. This change reduces the relative significance of resource depletion in the normalised results chart. As normalisation is not central to conclusions, the change only affects the charts noted.
Section 9.4 (Figures reflecting construction impact breakdown)	Double check the water use figures for houses c and d (the steel houses). The charts for these for Melbourne and Sydney are on pages 91 and 95 (there is no chart for Brisbane). It appears that the water use for the roof tiles is not included for these two houses. I'm not sure if this is a misprint or what.	The roof element "Roof (tiles)" noted in the construction breakdowns of the report does include framing as well. This is why there is a difference between steel frame and timber frame. Descriptions of building subsystems referred to in Figures 21 through 26 have been renamed to better reflect subsystem material content.
Table 19 and Table 51.	Please supply the water use for Table 51 Characterisation - 6 star performance for water use for the Melbourne houses to three decimal places (as it is for Sydney and Brisbane).	Decimal places increased.
Table 5	Most of the water used is classified as "water - unspecified natural origin". It appears that most of the water use included for timber products is associated with the diversion of rainwater into wood when compared to grassland (for softwood plantations) and conservation land (for hardwood). The description in Table 5 for the water use indicator is that "Net water use including potable, process and cooling water which may impact on water quality, water depletion, and biodiversity." This doesn't seem to adequately describe what water consumption is included for timber products.	A large section on water characterisation is included in Section 9.1.1. No change to text.
Table 9	Prior timber data referenced is not relevant and should be removed	Data removed. Only the data used is discussed.
General	Minor spelling and grammatical errors.	Corrected throughout.

Appendix K Normalisation and Characterisation Factors

Impact assessment Method				
Impact category				
Global Warming	kg CO2			
Compartment	Sub compartment	Substance	Factor	Unit
Air	(unspecified)	Carbon dioxide	1	kg
Soil	(unspecified)	Carbon dioxide, biogenic	-1	kg
Air	(unspecified)	Carbon dioxide, fossil	1	kg
Air	(unspecified)	Chlorinated fluorocarbons, hard	7100	kg
Air	(unspecified)	Chlorinated fluorocarbons, soft	1600	kg
Air	(unspecified)	Chloroform	25	kg
Air	(unspecified)	Dinitrogen monoxide	310	kg
Air	(unspecified)	Ethane, 1-chloro-1,1-difluoro-, HCFC-142	1800	kg
Air	(unspecified)	Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	580	kg
Air	(unspecified)	Ethane, 1,1-difluoro-, HFC-152a	150	kg
Air	(unspecified)	Ethane, 1,1,1-trichloro-, HCFC-140	100	kg
Air	(unspecified)	Ethane, 1,1,1-trifluoro-, HCFC-143a	3800	kg
Air	(unspecified)	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	1200	kg
Air	(unspecified)	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	4500	kg
Air	(unspecified)	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	7000	kg
Air	(unspecified)	Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	440	kg
Air	(unspecified)	Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	90	kg
Air	(unspecified)	Ethane, chloropentafluoro-, CFC-115	7000	kg
Air	(unspecified)	Ethane, hexafluoro-, HFC-116	9200	kg
Air	(unspecified)	Ethane, pentafluoro-, HFC-125	3400	kg
Air	(unspecified)	Methane	21	kg
Air	(unspecified)	Methane, biogenic	20	kg
Air	(unspecified)	Methane, bromochlorodifluoro-, Halon 1211	4900	kg
Air	(unspecified)	Methane, bromotrifluoro-, Halon 1301	4900	kg
Air	(unspecified)	Methane, chlorodifluoro-, HCFC-22	1600	kg
Air	(unspecified)	Methane, chlorotrifluoro-, CFC-13	13000	kg
Air	(unspecified)	Methane, dichloro-, HCC-30	15	kg
Air	(unspecified)	Methane, dichlorodifluoro-, CFC-12	7100	kg
Air	(unspecified)	Methane, tetrachloro-, CFC-10	1300	kg
Air	(unspecified)	Methane, tetrafluoro-, FC-14	6500	kg
Air	(unspecified)	Methane, trichlorofluoro-, CFC-11	3400	kg
Impact category				
Photochemical oxidation	kg C2H4			
Comnpartment	Sub compartment	Substance	Factor	Unit
Air	(unspecified)	1-Butanol	6.20E-01	kg
Air	(unspecified)	1-Butene	1.08E+00	kg
Air	(unspecified)	1-Butene, 2-methyl-	7.71E-01	kg
Air	(unspecified)	1-Butene, 3-methyl-	6.71E-01	kg
Air	(unspecified)	1-Hexene	8.74E-01	kg
Air	(unspecified)	1-Pentene	9.77E-01	kg
Air	(unspecified)	1-Propanol	5.61E-01	kg
Air	(unspecified)	2-Butanol	4.00E-01	kg
Air	(unspecified)	2-Butanone, 3-methyl-	4.90E-01	kg
Air	(unspecified)	2-Butanone, 3,3-dimethyl-	3.23E-01	kg
Air	(unspecified)	2-Butene (cis)	1.15E+00	kg
Air	(unspecified)	2-Butene (trans)	1.13E+00	kg
Air	(unspecified)	2-Butene, 2-methyl-	8.42E-01	kg
Air	(unspecified)	2-Hexanone	5.72E-01	kg
Air	(unspecified)	2-Hexene (cis)	1.07E+00	kg
Air	(unspecified)	2-Hexene (trans)	1.07E+00	kg
Air	(unspecified)	2-Pentanone	5.48E-01	kg
Air	(unspecified)	2-Pentene (cis)	1.12E+00	kg

Air	(unspecified)	2-Pentene (trans)	1.12E+00	kg
Air	(unspecified)	2-Propanol	1.88E-01	kg
Air	(unspecified)	3-Hexanone	5.99E-01	kg
Air	(unspecified)	3-Pentanol	5.95E-01	kg
Air	(unspecified)	Acetaldehyde	6.41E-01	kg
Air	(unspecified)	Acetic acid	9.70E-02	kg
Air	(unspecified)	Acetic acid, butyl ester	2.69E-01	kg
Air	(unspecified)	Acetic acid, ethyl ester	2.09E-01	kg
Air	(unspecified)	Acetic acid, methyl ester	5.90E-02	kg
Air	(unspecified)	Acetic acid, propyl ester	2.82E-01	kg
Air	(unspecified)	Acetone	9.40E-02	kg
Air	(unspecified)	Benzaldehde	-9.20E-02	kg
Air	(unspecified)	Benzene	2.20E-01	kg
Air	(unspecified)	Benzene, 1-propyl-	6.36E-01	kg
Air	(unspecified)	Benzene, 1,2,3-trimethyl-	1.27E+00	kg
Air	(unspecified)	Benzene, 1,2,4-trimethyl-	1.28E+00	kg
Air	(unspecified)	Benzene, 1,3,5-trimethyl-	1.38E+00	kg
Air	(unspecified)	Benzene, 3,5-dimethylethyl-	1.32E+00	kg
Air	(unspecified)	Benzene, ethyl-	7.30E-01	kg
Air	(unspecified)	Butadiene	8.50E-01	kg
Air	(unspecified)	Butanal	7.95E-01	kg
Air	(unspecified)	Butane	3.52E-01	kg
Air	(unspecified)	Butane, 2,2-dimethyl-	2.41E-01	kg
Air	(unspecified)	Butane, 2,3-dimethyl-	5.41E-01	kg
Air	(unspecified)	Butanol, 2-methyl-1-	4.89E-01	kg
Air	(unspecified)	Butanol, 2-methyl-2-	2.28E-01	kg
Air	(unspecified)	Butanol, 3-methyl-1-	4.33E-01	kg
Air	(unspecified)	Butanol, 3-methyl-2-	4.06E-01	kg
Air	(unspecified)	Carbon monoxide	2.70E-02	kg
Air	(unspecified)	Chloroform	2.30E-02	kg
Air	(unspecified)	Cumene	5.00E-01	kg
Air	(unspecified)	Cyclohexane	2.90E-01	kg
Air	(unspecified)	Cyclohexanol	5.18E-01	kg
Air	(unspecified)	Cyclohexanone	2.99E-01	kg
Air	(unspecified)	Decane	3.84E-01	kg
Air	(unspecified)	Diacetone alcohol	3.07E-01	kg
Air	(unspecified)	Diethyl ether	4.45E-01	kg
Air	(unspecified)	Diethyl ketone	4.14E-01	kg
Air	(unspecified)	Diisopropyl ether	3.98E-01	kg
Air	(unspecified)	Dimethyl carbonate	2.50E-02	kg
Air	(unspecified)	Dimethyl ether	1.89E-01	kg
Air	(unspecified)	Dodecane	3.57E-01	kg
Air	(unspecified)	Ethane	1.23E-01	kg
Air	(unspecified)	Ethane, 1,1,1-trichloro-, HCFC-140	9.00E-03	kg
Air	(unspecified)	Ethanol	3.99E-01	kg
Air	(unspecified)	Ethanol, 2-butoxy-	4.83E-01	kg
Air	(unspecified)	Ethanol, 2-ethoxy-	3.86E-01	kg
Air	(unspecified)	Ethanol, 2-methoxy-	3.07E-01	kg
Air	(unspecified)	Ethene	1.00E+00	kg
Air	(unspecified)	Ethene, dichloro- (cis)	4.47E-01	kg
Air	(unspecified)	Ethene, dichloro- (trans)	3.92E-01	kg
Air	(unspecified)	Ethene, tetrachloro-	2.90E-02	kg
Air	(unspecified)	Ethene, trichloro-	3.30E-01	kg
Air	(unspecified)	Ethylene glycol	3.73E-01	kg
Air	(unspecified)	Ethyne	8.50E-02	kg
Air	(unspecified)	Formaldehyde	5.20E-01	kg
Air	(unspecified)	Formic acid	3.20E-02	kg
Air	(unspecified)	Heptane	4.94E-01	kg
Air	(unspecified)	Hexane	4.82E-01	kg
Air	(unspecified)	Hexane, 2-methyl-	4.11E-01	kg
Air	(unspecified)	Hexane, 3-methyl-	3.64E-01	kg
Air	(unspecified)	Isobutanol	3.60E-01	kg
Air	(unspecified)	Isobutene	6.27E-01	kg
Air	(unspecified)	Isobutyraldehyde	5.14E-01	kg
Air	(unspecified)	Isopentane	4.05E-01	kg
Air	(unspecified)	Isoprene	1.09E+00	kg
Air	(unspecified)	Isopropyl acetate	2.11E-01	kg
Air	(unspecified)	m-Xylene	1.10E+00	kg
Air	(unspecified)	Methane	6.00E-03	kg
Air	(unspecified)	Methane, dichloro-, HCC-30	6.80E-02	kg
Air	(unspecified)	Methane, dimethoxy-	1.60E-01	kg
Air	(unspecified)	Methane, monochloro-, R-40	5.00E-03	kg

Air	(unspecified)	Methanol	1.40E-01	kg
Air	(unspecified)	Methyl ethyl ketone	3.73E-01	kg
Air	(unspecified)	Methyl formate	2.70E-02	kg
Air	(unspecified)	Nitric oxide	-4.27E-01	kg
Air	(unspecified)	Nitrogen dioxide	2.80E-02	kg
Air	(unspecified)	Nitrogen oxides	2.80E-02	kg
Air	(unspecified)	NMVOC, non-methane volatile organic compounds, unspecified origin	0.398	kg
Air	low. pop.	NMVOC, non-methane volatile organic compounds, unspecified origin	0	kg
Air	(unspecified)	Nonane	4.14E-01	kg
Air	(unspecified)	o-Xylene	1.10E+00	kg
Air	(unspecified)	Octane	4.53E-01	kg
Air	(unspecified)	p-Xylene	1.00E+00	kg
Air	(unspecified)	Pentanal	7.65E-01	kg
Air	(unspecified)	Pentane	3.95E-01	kg
Air	(unspecified)	Pentane, 2-methyl-	4.20E-01	kg
Air	(unspecified)	Pentane, 3-methyl-	4.79E-01	kg
Air	(unspecified)	Propanal	7.98E-01	kg
Air	(unspecified)	Propane	1.76E-01	kg
Air	(unspecified)	Propane, 2,2-dimethyl-	1.73E-01	kg
Air	(unspecified)	Propene	1.12E+00	kg
Air	(unspecified)	Propionic acid	1.50E-01	kg
Air	(unspecified)	Propylene glycol	4.57E-01	kg
Air	(unspecified)	Propylene glycol methyl ether	3.55E-01	kg
Air	(unspecified)	Propylene glycol t-butyl ether	4.63E-01	kg
Air	(unspecified)	Styrene	1.40E-01	kg
Air	(unspecified)	Sulfur dioxide	4.80E-02	kg
Air	(unspecified)	t-Butyl alcohol	1.06E-01	kg
Air	(unspecified)	t-Butyl ethyl ether	2.44E-01	kg
Air	(unspecified)	t-Butyl methyl ether	1.75E-01	kg
Air	(unspecified)	Toluene	6.40E-01	kg
Air	(unspecified)	Toluene, 2-ethyl-	8.98E-01	kg
Air	(unspecified)	Toluene, 3-ethyl-	1.02E+00	kg
Air	(unspecified)	Toluene, 3,5-diethyl-	1.30E+00	kg
Air	(unspecified)	Toluene, 4-ethyl-	9.06E-01	kg
Air	(unspecified)	Undecane	3.84E-01	kg
Air	(unspecified)	VOC, volatile organic compounds	0.398	kg
Impact category				
Eutrophication	kg PO4--- eq			
Comnpartment	Sub compartment	Substance	Factor	Unit
Air	(unspecified)	Ammonia	3.50E-01	kg
Water	(unspecified)	Ammonia	3.50E-01	kg
Water	ocean	Ammonia	3.50E-01	kg
Soil	agricultural	Ammonia	3.50E-01	kg
Soil	industrial	Ammonia	3.50E-01	kg
Air	(unspecified)	Ammonium, ion	3.30E-01	kg
Water	(unspecified)	Ammonium, ion	3.30E-01	kg
Water	ocean	Ammonium, ion	3.30E-01	kg
Soil	agricultural	Ammonium, ion	3.30E-01	kg
Soil	industrial	Ammonium, ion	3.30E-01	kg
Water	(unspecified)	COD, Chemical Oxygen Demand	2.20E-02	kg
Water	ocean	COD, Chemical Oxygen Demand	2.20E-02	kg
Air	(unspecified)	Nitrate	1.00E-01	kg
Water	(unspecified)	Nitrate	1.00E-01	kg
Water	ocean	Nitrate	1.00E-01	kg
Soil	agricultural	Nitrate	1.00E-01	kg
Soil	industrial	Nitrate	1.00E-01	kg
Air	(unspecified)	Nitric acid	1.00E-01	kg
Water	(unspecified)	Nitric acid	1.00E-01	kg
Water	ocean	Nitric acid	1.00E-01	kg
Soil	agricultural	Nitric acid	1.00E-01	kg
Soil	industrial	Nitric acid	1.00E-01	kg
Air	(unspecified)	Nitric oxide	2.00E-01	kg
Water	(unspecified)	Nitrite	1.00E-01	kg
Water	ocean	Nitrite	1.00E-01	kg
Air	(unspecified)	Nitrogen	4.20E-01	kg
Water	(unspecified)	Nitrogen	4.20E-01	kg

Water	ocean	Nitrogen	4.20E-01	kg
Soil	agricultural	Nitrogen	4.20E-01	kg
Soil	industrial	Nitrogen	4.20E-01	kg
Air	(unspecified)	Nitrogen dioxide	1.30E-01	kg
Air	(unspecified)	Nitrogen oxides	1.30E-01	kg
Air	low. pop.	Nitrogen oxides	1.30E-01	kg
Air	(unspecified)	Phosphate	1.00E+00	kg
Water	(unspecified)	Phosphate	1.00E+00	kg
Water	ocean	Phosphate	1.00E+00	kg
Soil	agricultural	Phosphate	1.00E+00	kg
Soil	industrial	Phosphate	1.00E+00	kg
Air	(unspecified)	Phosphoric acid	0.97	kg
Water	(unspecified)	Phosphoric acid	0.97	kg
Water	ocean	Phosphoric acid	0.97	kg
Soil	agricultural	Phosphoric acid	0.97	kg
Soil	industrial	Phosphoric acid	0.97	kg
Air	(unspecified)	Phosphorus	3.06E+00	kg
Water	(unspecified)	Phosphorus	3.06E+00	kg
Water	ocean	Phosphorus	3.06E+00	kg
Soil	agricultural	Phosphorus	3.06E+00	kg
Soil	industrial	Phosphorus	3.06E+00	kg
Air	(unspecified)	Phosphorus pentoxide	1.34	kg
Water	(unspecified)	Phosphorus pentoxide	1.34	kg
Water	ocean	Phosphorus pentoxide	1.34	kg
Soil	agricultural	Phosphorus pentoxide	1.34	kg
Soil	industrial	Phosphorus pentoxide	1.34	kg
Impact category				
Land use	Ha a			
Comnpartment	Sub compartment	Substance	Factor	Unit
Raw	land	Land use (100% occupied)	1	ha a
Raw	land	Land use (33% occupied)	1	ha a
Raw	in ground	Occupation ; urban ; continuously built	1	ha a
Raw	land	Occupation, arable	1	ha a
Raw	land	Occupation, arable, intensive	1	ha a
Raw	land	Occupation, arable, non-irrigated, diverse-intensive	1	ha a
Raw	land	Occupation, arable, organic	1	ha a
Raw	(unspecified)	Occupation, construction site	1	ha a
Raw	land	Occupation, dump site	1	ha a
Raw	(unspecified)	Occupation, dump site, benthos	1	ha a
Raw	(unspecified)	Occupation, dump site, radioactive	1	ha a
Raw	(unspecified)	Occupation, dump site, radioactive, high	1	ha a
Raw	(unspecified)	Occupation, dump site, radioactive, low-medium	1	ha a
Raw	land	Occupation, forest	1	ha a
Raw	land	Occupation, forest, extensive	1	ha a
Raw	land	Occupation, forest, intensive	1	ha a
Raw	land	Occupation, forest, intensive, clear-cutting	1	ha a
Raw	land	Occupation, forest, intensive, normal	1	ha a
Raw	land	Occupation, forest, intensive, short-cycle	1	ha a
Raw	(unspecified)	Occupation, heterogeneous, agricultural	1	ha a
Raw	land	Occupation, industrial area	1	ha a
Raw	(unspecified)	Occupation, industrial area, benthos	1	ha a
Raw	(unspecified)	Occupation, industrial area, built up	1	ha a
Raw	(unspecified)	Occupation, industrial area, vegetation	1	ha a
Raw	land	Occupation, mineral extraction site	1	ha a
Raw	(unspecified)	Occupation, oil and gas extraction site	1	ha a
Raw	(unspecified)	Occupation, pasture and meadow	1	ha a
Raw	land	Occupation, pasture and meadow, extensive	1	ha a
Raw	land	Occupation, pasture and meadow, intensive	1	ha a
Raw	land	Occupation, pasture and meadow, organic	1	ha a
Raw	(unspecified)	Occupation, pipelines	1	ha a
Raw	land	Occupation, traffic area	1	ha a
Raw	(unspecified)	Occupation, traffic area, rail embankment	1	ha a
Raw	(unspecified)	Occupation, traffic area, rail network	1	ha a
Raw	(unspecified)	Occupation, traffic area, road embankment	1	ha a
Raw	(unspecified)	Occupation, traffic area, road network	1	ha a
Raw	land	Occupation, unknown	1	ha a
Raw	in ground	Occupation, urban, continuously built	1	m2a
Raw	land	Occupation, urban, continuously built	1	ha a

Raw	land	Occupation, urban, discontinuously built	1	ha a
Raw	land	Occupation, urban, green areas	1	ha a
Raw	land	Occupation, water bodies, artificial	1	ha a
Impact category				
Water Use	KL H2O			
Comnpartment	Sub compartment	Substance	Factor	Unit
Raw	(unspecified)	Water, cooling	1	m3
Raw	(unspecified)	Water, cooling, drinking	1	tonne
Raw	(unspecified)	Water, cooling, river	1	tonne
Raw	(unspecified)	Water, cooling, salt, ocean	1	tonne
Raw	(unspecified)	Water, cooling, surface	1	tonne
Raw	(unspecified)	Water, cooling, unspecified natural origin/kg	1	tonne
Raw	(unspecified)	Water, cooling, unspecified natural origin/m3	1	m3
Raw	(unspecified)	Water, cooling, unspecified/kg	1	tonne
Raw	(unspecified)	Water, cooling, well, in ground	1	tonne
Raw	(unspecified)	Water, cooling/kg	1	tonne
Raw	(unspecified)	Water, cooling/m3	1	m3
Raw	(unspecified)	Water, drinking	1	tonne
Raw	(unspecified)	Water, fresh	1	m3
Raw	(unspecified)	Water, from Victorian catchments	1	m3
Raw	(unspecified)	Water, lake	1	m3
Raw	(unspecified)	Water, mining, unspecified natural origin/m3	1	m3
Raw	(unspecified)	Water, process	1	m3
Raw	(unspecified)	Water, process and cooling, unspecified natural origin	1	m3
Raw	(unspecified)	Water, process, drinking	1	tonne
Raw	(unspecified)	Water, process, river	1	tonne
Raw	(unspecified)	Water, process, salt, ocean	1	tonne
Raw	(unspecified)	Water, process, surface	1	tonne
Raw	(unspecified)	Water, process, unspecified natural origin/kg	1	tonne
Raw	(unspecified)	Water, process, unspecified natural origin/m3	1	m3
Raw	(unspecified)	Water, process, well, in ground	1	tonne
Raw	(unspecified)	Water, process/kg	1	tonne
Raw	(unspecified)	Water, process/m3	1	m3
Raw	(unspecified)	Water, reticulated supply	1	m3
Raw	(unspecified)	Water, river	1	m3
Raw	(unspecified)	Water, stormwater	1	tonne
Raw	(unspecified)	Water, surface	1	tonne
Raw	(unspecified)	Water, unspecified natural origin /kg	1	tonne
Raw	(unspecified)	Water, unspecified natural origin/kg	1	tonne
Raw	(unspecified)	Water, unspecified natural origin/m3	1	m3
Raw	(unspecified)	Water, well, in ground	1	m3
Raw	(unspecified)	Water, well, in ground /kg	1	tonne
Raw	(unspecified)	Water, well, in ground/m3	1	m3
Impact category				
Solid waste	kg			
Comnpartment	Sub compartment	Substance	Factor	Unit
Waste	(unspecified)	Aluminium waste	1	kg
Waste	(unspecified)	Asbestos	1	kg
Waste	(unspecified)	ash	1	kg
Waste	(unspecified)	Calcium fluoride waste	1	kg
Waste	(unspecified)	cardboard	1	kg
Waste	(unspecified)	Cathode iron ingots waste	1	kg
Waste	(unspecified)	Cathode loss	1	kg
Waste	(unspecified)	Chemical waste, inert	1	kg
Waste	(unspecified)	Chemical waste, regulated	1	kg
Waste	(unspecified)	Chemical waste, unspecified	1	kg
Waste	(unspecified)	Chromium waste	1	kg
Waste	(unspecified)	Coal tailings	1	kg
Waste	(unspecified)	Copper waste	1	kg
Waste	(unspecified)	Dross	1	kg
Waste	(unspecified)	Dust, unspecified	1	kg
Waste	(unspecified)	Glass waste	1	kg
Waste	(unspecified)	gypsum	1	kg
Waste	(unspecified)	Iron waste	1	kg

Waste	(unspecified)	jarosite	1	kg
Waste	(unspecified)	limestone	1	kg
Waste	(unspecified)	Metal waste	1	kg
Waste	(unspecified)	Mineral waste	1	kg
Waste	(unspecified)	Mineral waste, from mining	1	kg
Waste	(unspecified)	Monasite	1	kg
Waste	(unspecified)	Neutralized Acid Effluent	1	kg
Waste	(unspecified)	non magenetic fines	1	kg
Waste	(unspecified)	Oil waste	1	kg
Waste	(unspecified)	Packaging waste, paper and board	1	kg
Waste	(unspecified)	Packaging waste, plastic	1	kg
Waste	(unspecified)	Packaging waste, steel	1	kg
Waste	(unspecified)	Packaging waste, unspecified	1	kg
Waste	(unspecified)	Packaging waste, wood	1	kg
Waste	(unspecified)	Plastic waste	1	kg
Waste	(unspecified)	Polyethylene waste	1	kg
Waste	(unspecified)	Polyvinyl chloride waste	1	kg
Waste	(unspecified)	Production waste	1	kg
Waste	(unspecified)	Production waste, not inert	1	kg
Waste	(unspecified)	Rejects	1	kg
Waste	(unspecified)	Rejects, corrugated cardboard	1	kg
Waste	(unspecified)	Slags	1	kg
Waste	(unspecified)	Slags and ashes	1	kg
Waste	(unspecified)	Soot	1	kg
Waste	(unspecified)	Steel waste	1	kg
Waste	(unspecified)	Stones and rubble	1	kg
Waste	(unspecified)	Tails	1	kg
Waste	(unspecified)	Tin waste	1	kg
Waste	(unspecified)	Tinder from rolling drum	1	kg
Waste	(unspecified)	Waste in bioactive landfill	1	kg
Waste	(unspecified)	Waste, final, inert	1	kg
Waste	(unspecified)	Waste, fly ash	1	kg
Waste	(unspecified)	Waste, from construction	1	kg
Waste	(unspecified)	Waste, from incinerator	1	kg
Waste	(unspecified)	Waste, household	1	kg
Waste	(unspecified)	Waste, industrial	1	kg
Waste	(unspecified)	Waste, Inert	1	kg
Waste	(unspecified)	Waste, inorganic	1	kg
Waste	(unspecified)	Waste, limestone	1	kg
Waste	(unspecified)	Waste, Shedder dust	1	kg
Waste	(unspecified)	Waste, sludge	1	kg
Waste	(unspecified)	Waste, solid	1	kg
Waste	(unspecified)	Waste, to incineration	1	kg
Waste	(unspecified)	Waste, toxic	1	kg
Waste	(unspecified)	Waste, unspecified	1	kg
Waste	(unspecified)	Wood and wood waste	1	tonne
Waste	(unspecified)	Wood, sawdust	1	kg
Waste	(unspecified)	Zinc waste	1	kg
Impact category				
Resource depletion	MJ Surplus			
Comnpartment	Sub compartment	Substance	Factor	Unit
Raw	(unspecified)	Aluminium, 24% in bauxite, 11% in crude ore, in ground	2.38	kg
Raw	(unspecified)	Aluminium, in ground	2.38	kg
Raw	(unspecified)	Bauxite, in ground	0.5	kg
Raw	(unspecified)	Chromium ore, in ground	0.275	kg
Raw	(unspecified)	Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	0.9165	kg
Raw	(unspecified)	Chromium, in ground	0.9165	kg
Raw	(unspecified)	Cinnabar, in ground	165.5	kg
Raw	(unspecified)	Coal, 13.3 MJ per kg, in ground	1.1	kg
Raw	(unspecified)	Coal, 18 MJ per kg, in ground	1.25	kg
Raw	(unspecified)	Coal, 18.0 MJ per kg, in ground	1.25	kg
Raw	(unspecified)	Coal, 18.5 MJ per kg, in ground	1.25	kg
Raw	(unspecified)	Coal, 19.5 MJ per kg, in ground	1.355	kg
Raw	(unspecified)	Coal, 20.0 MJ per kg, in ground	1.389	kg
Raw	(unspecified)	Coal, 20.5 MJ per kg, in ground	1.39	kg

Raw	(unspecified)	Coal, 21.5 MJ per kg, in ground	1.4	kg
Raw	(unspecified)	Coal, 22.1 MJ per kg, in ground	1.535	kg
Raw	(unspecified)	Coal, 22.4 MJ per kg, in ground	1.556	kg
Raw	(unspecified)	Coal, 22.6 MJ per kg, in ground	1.57	kg
Raw	(unspecified)	Coal, 22.8 MJ per kg, in ground	1.57	kg
Raw	(unspecified)	Coal, 23.0 MJ per kg, in ground	1.598	kg
Raw	(unspecified)	Coal, 24.0 MJ per kg, in ground	1.67	kg
Raw	(unspecified)	Coal, 24.1 MJ per kg, in ground	1.674	kg
Raw	(unspecified)	Coal, 26.4 MJ per kg, in ground	1.834	kg
Raw	(unspecified)	Coal, 27.1 MJ per kg, in ground	1.882	kg
Raw	(unspecified)	Coal, 28.0 MJ per kg, in ground	1.945	kg
Raw	(unspecified)	Coal, 28.6 MJ per kg, in ground	1.987	kg
Raw	(unspecified)	Coal, 29.0 MJ per kg, in ground	2.014	kg
Raw	(unspecified)	Coal, 29.3 MJ per kg, in ground	2.035	kg
Raw	(unspecified)	Coal, 30.3 MJ per kg, in ground	2.105	kg
Raw	(unspecified)	Coal, 30.6 MJ per kg, in ground	2.126	kg
Raw	(unspecified)	Coal, brown, 10 MJ per kg, in ground	0.61	kg
Raw	(unspecified)	Coal, brown, 10.0 MJ per kg, in ground	0.61	kg
Raw	(unspecified)	Coal, brown, 14.1 MJ per kg, in ground	0.86	kg
Raw	(unspecified)	Coal, brown, 14.4 MJ per kg, in ground	0.9	kg
Raw	(unspecified)	Coal, brown, 15 MJ per kg, in ground	1.2	kg
Raw	(unspecified)	Coal, brown, 15.0 MJ per kg, in ground	0.915	kg
Raw	(unspecified)	Coal, brown, 7.9 MJ per kg, in ground	0.482	kg
Raw	(unspecified)	Coal, brown, 8 MJ per kg, in ground	0.458	kg
Raw	(unspecified)	Coal, brown, 8.0 MJ per kg, in ground	0.488	kg
Raw	(unspecified)	Coal, brown, 8.1 MJ per kg, in ground	0.494	kg
Raw	(unspecified)	Coal, brown, 8.2 MJ per kg, in ground	0.5	kg
Raw	(unspecified)	Coal, brown, 9.9 MJ per kg, in ground	0.604	kg
Raw	(unspecified)	Coal, brown, in ground	0.6039	kg
Raw	(unspecified)	Coal, feedstock, 26.4 MJ per kg, in ground	1.83	kg
Raw	(unspecified)	Coal, hard, unspecified, in ground	1.32	kg
Raw	(unspecified)	Copper ore, in ground	0.415	kg
Raw	(unspecified)	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	36.79576	kg
Raw	(unspecified)	Copper, in ground	36.7	kg
Raw	(unspecified)	Energy, from coal	6.96E-02	MJ
Raw	(unspecified)	Energy, from coal, brown	6.10E-02	MJ
Raw	(unspecified)	Energy, from gas, natural	8.90E-02	MJ
Raw	(unspecified)	Energy, from liquified petroleum gas, feedstock	8.90E-02	MJ
Raw	(unspecified)	Energy, from oil	8.30E-02	MJ
Raw	(unspecified)	Gas, mine, off-gas, process, coal mining/kg	3.9	kg
Raw	(unspecified)	Gas, mine, off-gas, process, coal mining/m3	3.196	m3
Raw	(unspecified)	Gas, natural, 30.3 MJ per kg, in ground	2.69	kg
Raw	(unspecified)	Gas, natural, 31.65 MJ per m3, in ground	2.817	m3
Raw	(unspecified)	Gas, natural, 35 MJ per m3, in ground	3.115	m3
Raw	(unspecified)	Gas, natural, 35.0 MJ per m3, in ground	3.115	m3
Raw	(unspecified)	Gas, natural, 35.2 MJ per m3, in ground	3.133	m3
Raw	(unspecified)	Gas, natural, 35.9 MJ per m3, in ground	3.133	m3
Raw	(unspecified)	Gas, natural, 36.6 MJ per m3, in ground	3.26	m3
Raw	(unspecified)	Gas, natural, 38.8 MJ per m3, in ground	3.453	m3
Raw	(unspecified)	Gas, natural, 39.0 MJ per m3, in ground	3.471	m3
Raw	(unspecified)	Gas, natural, 42.0 MJ per m3, in ground	3.7	m3
Raw	(unspecified)	Gas, natural, 46.8 MJ per kg, in ground	4.17	kg
Raw	(unspecified)	Gas, natural, 50.3 MJ per kg, in ground	2.697	kg
Raw	(unspecified)	Gas, natural, 51.3 MJ per kg, in ground	2.697	kg
Raw	(unspecified)	Gas, natural, feedstock, 35 MJ per m3, in ground	3.12	m3
Raw	(unspecified)	Gas, natural, feedstock, 35.0 MJ per m3, in ground	3.12	m3
Raw	(unspecified)	Gas, natural, feedstock, 46.8 MJ per kg, in ground	4.17	kg
Raw	(unspecified)	Gas, natural, in ground	3.236	m3
Raw	(unspecified)	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	3.115	m3
Raw	(unspecified)	Gas, off-gas, oil production, in ground	3.115	m3
Raw	(unspecified)	Gas, petroleum, 35 MJ per m3, in ground	3.115	m3
Raw	(unspecified)	Iron ore, in ground	0.029	kg
Raw	(unspecified)	Iron, 46% in ore, 25% in crude ore, in ground	0.051	kg
Raw	(unspecified)	Iron, in ground	0.051	kg
Raw	(unspecified)	Lead ore, in ground	0.368	kg
Raw	(unspecified)	Lead, in ground	7.35	kg
Raw	(unspecified)	Manganese ore, in ground	0.141	kg
Raw	(unspecified)	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	0.313	kg
Raw	(unspecified)	Manganese, in ground	0.313	kg
Raw	(unspecified)	Mercury, in ground	165.5	kg

Raw	(unspecified)	Molybdenum ore, in ground	0.041	kg
Raw	(unspecified)	Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude ore, in ground	37.14	kg
Raw	(unspecified)	Molybdenum, in ground	41	kg
Raw	(unspecified)	Nickel ore, in ground	0.356	kg
Raw	(unspecified)	Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground	16.32	kg
Raw	(unspecified)	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	16.32	kg
Raw	(unspecified)	Nickel, in ground	23.75	kg
Raw	(unspecified)	Oil, crude, 38400 MJ per m3, in ground	3.4	l
Raw	(unspecified)	Oil, crude, 41 MJ per kg, in ground	34	kg
Raw	(unspecified)	Oil, crude, 41.0 MJ per kg, in ground	3.403	kg
Raw	(unspecified)	Oil, crude, 41.9 MJ per kg, in ground	3.478	kg
Raw	(unspecified)	Oil, crude, 42.0 MJ per kg, in ground	3.486	kg
Raw	(unspecified)	Oil, crude, 42.6 MJ per kg, in ground	3.536	kg
Raw	(unspecified)	Oil, crude, 42.7 MJ per kg, in ground	3.54	kg
Raw	(unspecified)	Oil, crude, 42.8 MJ per kg, in ground	3.54	kg
Raw	(unspecified)	Oil, crude, 43.4 MJ per kg, in ground	3.54	kg
Raw	(unspecified)	Oil, crude, 44.0 MJ per kg, in ground	3.652	kg
Raw	(unspecified)	Oil, crude, 44.6 MJ per kg, in ground	3.702	kg
Raw	(unspecified)	Oil, crude, 45.0 MJ per kg, in ground	3.735	kg
Raw	(unspecified)	Oil, crude, feedstock, 41 MJ per kg, in ground	3.403	kg
Raw	(unspecified)	Oil, crude, feedstock, 42 MJ per kg, in ground	3.486	kg
Raw	(unspecified)	Oil, crude, in ground	3.59	kg
Raw	(unspecified)	Oil, from technosphere	3.59	kg
Raw	(unspecified)	Pyrolusite, in ground	0.313	kg
Raw	(unspecified)	Tin ore, in ground	0.06	kg
Raw	(unspecified)	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	600	kg
Raw	(unspecified)	Tin, in ground	600	kg
Raw	(unspecified)	Tungsten ore, in ground	0.927	kg
Raw	(unspecified)	Zinc 9%, Lead 5%, in sulfide, in ground	3.8367	kg
Raw	(unspecified)	Zinc ore, in ground	0.0164	kg
Raw	(unspecified)	Zinc, in ground	4.09	kg
Impact category				
Embodied energy LHV	MJ LHV			
Comnpartment	Sub compartment	Substance	Factor	Unit
Raw	(unspecified)	bagasse	8.7	kg
Raw	(unspecified)	Biomass	15	kg
Raw	(unspecified)	Biomass, feedstock	1	MJ
Raw	(unspecified)	Carbon	51	kg
Raw	(unspecified)	Coal, 13.3 MJ per kg, in ground	13.3	kg
Raw	(unspecified)	Coal, 18 MJ per kg, in ground	18	kg
Raw	(unspecified)	Coal, 18.0 MJ per kg, in ground	18	kg
Raw	(unspecified)	Coal, 18.5 MJ per kg, in ground	18.5	kg
Raw	(unspecified)	Coal, 19.5 MJ per kg, in ground	19.5	kg
Raw	(unspecified)	Coal, 20.0 MJ per kg, in ground	20	kg
Raw	(unspecified)	Coal, 20.5 MJ per kg, in ground	20.5	kg
Raw	(unspecified)	Coal, 21.5 MJ per kg, in ground	21.5	kg
Raw	(unspecified)	Coal, 22.1 MJ per kg, in ground	22.1	kg
Raw	(unspecified)	Coal, 22.4 MJ per kg, in ground	22.4	kg
Raw	(unspecified)	Coal, 22.6 MJ per kg, in ground	22.6	kg
Raw	(unspecified)	Coal, 22.8 MJ per kg, in ground	22.8	kg
Raw	(unspecified)	Coal, 23.0 MJ per kg, in ground	23	kg
Raw	(unspecified)	Coal, 24.0 MJ per kg, in ground	24	kg
Raw	(unspecified)	Coal, 24.1 MJ per kg, in ground	24.1	kg
Raw	(unspecified)	Coal, 26.4 MJ per kg, in ground	26.4	kg
Raw	(unspecified)	Coal, 27.1 MJ per kg, in ground	27.1	kg
Raw	(unspecified)	Coal, 28.0 MJ per kg, in ground	28	kg
Raw	(unspecified)	Coal, 28.6 MJ per kg, in ground	28.6	kg
Raw	(unspecified)	Coal, 29.0 MJ per kg, in ground	29	kg
Raw	(unspecified)	Coal, 29.3 MJ per kg, in ground	29.3	kg
Raw	(unspecified)	Coal, 30.3 MJ per kg, in ground	30.3	kg
Raw	(unspecified)	Coal, 30.6 MJ per kg, in ground	30.6	kg
Raw	(unspecified)	Coal, brown, 10 MJ per kg, in ground	10	kg
Raw	(unspecified)	Coal, brown, 10.0 MJ per kg, in ground	10	kg
Raw	(unspecified)	Coal, brown, 14.1 MJ per kg, in ground	14.1	kg

Raw	(unspecified)	Coal, brown, 14.4 MJ per kg, in ground	14.4	kg
Raw	(unspecified)	Coal, brown, 15 MJ per kg, in ground	15	kg
Raw	(unspecified)	Coal, brown, 15.0 MJ per kg, in ground	15	kg
Raw	(unspecified)	Coal, brown, 7.9 MJ per kg, in ground	7.9	kg
Raw	(unspecified)	Coal, brown, 8 MJ per kg, in ground	8	kg
Raw	(unspecified)	Coal, brown, 8.0 MJ per kg, in ground	8	kg
Raw	(unspecified)	Coal, brown, 8.1 MJ per kg, in ground	8.1	kg
Raw	(unspecified)	Coal, brown, 8.2 MJ per kg, in ground	8.2	kg
Raw	(unspecified)	Coal, brown, 9.9 MJ per kg, in ground	9.9	kg
Raw	(unspecified)	Coal, brown, in ground	12	kg
Raw	(unspecified)	Coal, feedstock, 26.4 MJ per kg, in ground	26.4	kg
Raw	(unspecified)	Coal, hard, unspecified, in ground	24	kg
Raw	(unspecified)	Energy, from ADO	1	MJ
Raw	(unspecified)	Energy, from Auto gasoline-leaded	1	MJ
Raw	(unspecified)	Energy, from Auto gasoline-unleaded	1	MJ
Raw	(unspecified)	Energy, from Aviation gasoline	1	MJ
Raw	(unspecified)	Energy, from Aviation turbine fuel	1	MJ
Raw	(unspecified)	Energy, from bagasse	1	MJ
Raw	(unspecified)	Energy, from biomass	1	MJ
Raw	(unspecified)	Energy, from brown coal briquetts	1	MJ
Raw	(unspecified)	Energy, from coal	1	MJ
Raw	in ground	Energy, from coal	1	MJ
Raw	(unspecified)	Energy, from coal byproducts	1	MJ
Raw	(unspecified)	Energy, from coal, brown	1	MJ
Raw	in ground	Energy, from coal, brown	1	MJ
Raw	(unspecified)	Energy, from coke	1	MJ
Raw	(unspecified)	Energy, from Fuel oil	1	MJ
Raw	(unspecified)	Energy, from gas, natural	1	MJ
Raw	in ground	Energy, from gas, natural	1	MJ
Raw	(unspecified)	Energy, from geothermal	1	MJ
Raw	(unspecified)	Energy, from Heating oil	1	MJ
Raw	(unspecified)	Energy, from hydro power	1	MJ
Raw	(unspecified)	Energy, from hydrogen	1	MJ
Raw	(unspecified)	Energy, from IDF	1	MJ
Raw	(unspecified)	Energy, from Lighting kerosene	1	MJ
Raw	(unspecified)	Energy, from liquified petroleum gas, feedstock	1	MJ
Raw	(unspecified)	Energy, from LPG	1	MJ
Raw	(unspecified)	Energy, from Natural gas	1	MJ
Raw	(unspecified)	Energy, from oil	1	MJ
Raw	in ground	Energy, from oil	1	MJ
Raw	(unspecified)	Energy, from peat	1	MJ
Raw	(unspecified)	Energy, from Petroleum products nec	1	MJ
Raw	(unspecified)	Energy, from Power kerosene	1	MJ
Raw	(unspecified)	Energy, from solar	1	MJ
Raw	(unspecified)	Energy, from sulfur	1	MJ
Raw	(unspecified)	Energy, from tidal	1	MJ
Raw	(unspecified)	Energy, from Town gas	1	MJ
Raw	(unspecified)	Energy, from uranium	1	MJ
Raw	in ground	Energy, from uranium	1	MJ
Raw	(unspecified)	Energy, from waves	1	MJ
Raw	(unspecified)	Energy, from wood	1	MJ
Raw	(unspecified)	Energy, geothermal	1	MJ
Raw	(unspecified)	Energy, gross calorific value, in biomass	0.904762	MJ
Raw	(unspecified)	Energy, in Solvents	1	MJ
Raw	(unspecified)	Energy, kinetic, flow, in wind	1	MJ
Raw	(unspecified)	Energy, potential, stock, in barrage water	1	MJ
Raw	(unspecified)	Energy, recovered	1	MJ
Raw	(unspecified)	Energy, unspecified	1	MJ
Raw	(unspecified)	Gas, natural, 30.3 MJ per kg, in ground	30.3	kg
Raw	(unspecified)	Gas, natural, 31.65 MJ per m3, in ground	31.65	m3
Raw	(unspecified)	Gas, natural, 35 MJ per m3, in ground	35	m3
Raw	(unspecified)	Gas, natural, 35.0 MJ per m3, in ground	35	m3
Raw	(unspecified)	Gas, natural, 35.2 MJ per m3, in ground	35.2	m3
Raw	(unspecified)	Gas, natural, 35.9 MJ per m3, in ground	35.9	m3
Raw	(unspecified)	Gas, natural, 36.6 MJ per m3, in ground	36.6	m3
Raw	(unspecified)	Gas, natural, 38.8 MJ per m3, in ground	38.8	m3
Raw	(unspecified)	Gas, natural, 39.0 MJ per m3, in ground	39	m3
Raw	(unspecified)	Gas, natural, 42.0 MJ per m3, in ground	42	m3
Raw	(unspecified)	Gas, natural, 46.8 MJ per kg, in ground	46.8	kg
Raw	(unspecified)	Gas, natural, 50.3 MJ per kg, in ground	50.3	kg
Raw	(unspecified)	Gas, natural, 51.3 MJ per kg, in ground	51.3	kg
Raw	(unspecified)	Gas, natural, feedstock, 35 MJ per m3, in ground	35	m3

Raw	(unspecified)	Gas, natural, feedstock, 35.0 MJ per m3, in ground	35	m3
Raw	(unspecified)	Gas, natural, feedstock, 46.8 MJ per kg, in ground	46.8	kg
Raw	(unspecified)	Gas, natural, in ground	35	m3
Raw	(unspecified)	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	35	m3
Raw	(unspecified)	Gas, off-gas, oil production, in ground	35	m3
Raw	(unspecified)	Gas, petroleum, 35 MJ per m3, in ground	35	m3
Raw	(unspecified)	Graphite, from technosphere	50	kg
Raw	(unspecified)	Methane	35.9	kg
Raw	(unspecified)	Mining gas, 30 MJ per kg	30	kg
Raw	(unspecified)	Oil, crude, 38400 MJ per m3, in ground	38400	m3
Raw	(unspecified)	Oil, crude, 41 MJ per kg, in ground	41	kg
Raw	(unspecified)	Oil, crude, 41.0 MJ per kg, in ground	41	kg
Raw	(unspecified)	Oil, crude, 41.9 MJ per kg, in ground	41.9	kg
Raw	(unspecified)	Oil, crude, 42.0 MJ per kg, in ground	42	kg
Raw	(unspecified)	Oil, crude, 42.6 MJ per kg, in ground	42.6	kg
Raw	(unspecified)	Oil, crude, 42.7 MJ per kg, in ground	42.7	kg
Raw	(unspecified)	Oil, crude, 42.8 MJ per kg, in ground	42.8	kg
Raw	(unspecified)	Oil, crude, 43.4 MJ per kg, in ground	43.4	kg
Raw	(unspecified)	Oil, crude, 44.0 MJ per kg, in ground	44	kg
Raw	(unspecified)	Oil, crude, 44.6 MJ per kg, in ground	44.6	kg
Raw	(unspecified)	Oil, crude, 45.0 MJ per kg, in ground	45	kg
Raw	(unspecified)	Oil, crude, feedstock, 41 MJ per kg, in ground	41	kg
Raw	(unspecified)	Oil, crude, feedstock, 42 MJ per kg, in ground	42	kg
Raw	(unspecified)	Oil, crude, in ground	45	kg
Raw	(unspecified)	Oil, from technosphere	42	kg
Raw	(unspecified)	Petroleum, from technosphere	38	kg
Raw	(unspecified)	Secondary wood	15.3	kg
Raw	(unspecified)	Uranium ore, 1.11 GJ per kg, in ground	1110	kg
Raw	(unspecified)	Uranium, 2291 GJ per kg, in ground	451000	kg
Raw	(unspecified)	Uranium, 336 GJ per kg, in ground	336000	kg
Raw	(unspecified)	Uranium, 451 GJ per kg, in ground	451000	kg
Raw	(unspecified)	Uranium, 560 GJ per kg, in ground	451000	kg
Raw	(unspecified)	Uranium, in ground	451000	kg
Raw	(unspecified)	Water, barrage	0.01	kg
Raw	(unspecified)	Water, through turbine	0.01	l
Raw	(unspecified)	Wood and cardboard waste	15.3	kg
Raw	(unspecified)	Wood and wood waste	15.3	kg
Raw	(unspecified)	Wood, feedstock	15.3	kg
Raw	(unspecified)	Wood, unspecified, standing/kg	15.3	kg
Normalization-Weighting set				
Australian annual per capita				
Normalization				
Global Warming	0.00003832			
Photochemical oxidation	0.139456933			
Eutrophication	0.070572141			
Land use	0.041999634			
Water Use	0.001103			
Solid waste	0.00072			
Resource depletion	1.88E-5			
Embodied energy LHV	1.30E-06			

Appendix L Non assessed substance check

A non-assessed substance check was completed and is available in a separate excel file.

ADDENDUM: Construction Type Costing

Following completion of the LCA report above, FWPA contracted Peter Karos at Davis Langdon to undertake a detailed costing of each of the construction types assessed in the report.

Costing was based solely on relevant information presented within the LCA report, and the necessary assumptions of Davis Langdon.

The cost analysis seeks to identify likely cost differences between the construction types and locations considered in the LCA report above.

The costing was completed after the peer review process had concluded so **HAS NOT BEEN PEER REVIEWED**.

The costing study is included in this addendum for the purposes of report completeness, and for future reference.

The Davis Langdon report is also available as a PDF for download from this site in a separate file. Please refer to report attachments for download.

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