Life Cycle Assessment of the Witchcliffe Ecovillage Passive Solar Cottage Lot Base Case Design and Design Options

June 2020

Life Cycle Logic

Title: Life Cycle Assessment of the Witchcliffe Ecovillage Passive Solar Cottage Lot Base Case Design and Design Options

Prepared for: Sustainable Settlements Pty Ltd

Date: 17 June 2020

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Document Management

Date	Version	Author	Description
11/10/2019	0.1	Andrew D Moore	Document created
7/11/2019	1.0	Andrew D Moore	Plans updated, units for CO_2 changed to kg, thermal assessment results added for internal brick walls, LCA explanation expanded.
16/6/2020	1.1	Andrew D Moore	Feedback from 3rd party review incorporated. Please refer to the Critical Review Statement in Appendix A for details. Update lime dataset and results for Hempcrete and Strawbale (lime render). See LCI section for details.
17/6/2020	1.2	Andrew D Moore	Reviewer Statement and EN15978 results table added to the appendices.

EXECUTIVE SUMMARY

Sustainable Settlements Pty Ltd commissioned Life Cycle Logic to conduct a Life Cycle Assessment (LCA) study to inform the development of the Design Guidelines for the Witchcliffe Ecovillage. The study aimed to conduct a LCA on a Base Case building design which would act as a benchmark against which a range of Design Options could be compared.

WITCHCLIFFE ECOVILLAGE

The Witchcliffe Ecovillage is a sustainable community that will be located 10 km south of Margaret River in Western Australia. The vision for the Ecovillage is to create a model of a highly sustainable, self-reliant community in a regional village setting, incorporating the best of 21st century technology and human settlement design to enable the Ecovillage community to produce as much energy as it consumes; be self-sufficient in water; care for the local environment; generate ongoing economic and social opportunities for the area; be socially diverse; and be self-sufficient in fresh food produce (Witchcliffe Ecovillage 2017).

DESIGN GUIDELINES

A set of building Design Guidelines are being developed for the Ecovillage to ensure that the built form and landscaping of the Ecovillage reflects the strong vision of sustainability and the clear character set for the development. They will provide straightforward guidelines that will apply to all residential and commercial buildings in the Ecovillage. They will help owners, designers and builders create aesthetically harmonious buildings which are passive solar, efficient, affordable, and comfortable to live and work in (Sustainable Settlements 2019).

LIFE CYCLE ASSESSMENT

LCA is a methodology which quantifies the environmental impacts of a product over its life, from cradle-to-grave, to provide greater understanding and to identify areas for further improvement. This study follows the requirements of the International standards for life cycle assessment ISO 14040:(2006a), ISO 14044:(2006b) and the environmental performance of buildings EN 15978:(2011).

GOAL AND SCOPE

The LCA study was based on a typical three-bedroom two-bathroom passive solar house designed for a Cottage Lot. The scope of the Base Case design included:

- Slab on grade foundation
- Cavity-brick construction with sand render exterior finish and standard wet plaster and conventional paint on interior

- Colorbond roofing
- Single glazed standard aluminium windows
- Rockwool ceiling insulation (R6.0)
- Synthetic carpets in bedrooms
- Tiles in living spaces and wet areas

Additional items have been included in the Base Case Design to ensure that more than 99% of the building (by mass and energy) has been included in the assessment. Of these additional items, the most significant are: Reverser cycle air-conditioning system for the living space (kitchen, dining and lounge), Refrigerator(s) and freezer, High-efficiency Appliances (televisions, dishwasher, washing machine, clothes dryer, computers, miscellaneous).

The key sustainability features included in the Base Case Design are:

- Passive solar design (all lots are oriented for solar access)
- 6.6 kWp photovoltaic (PV) solar system, (with shared battery storage[1])
- Rainwater storage tanks with pressure pump and ultraviolet water treatment system (there is no mains/scheme water supply connection)
- Heat pump hot water system (315 L, high COP, CO_2 refrigerant)

Several Design Options were investigated for walls, cladding, windows, ceiling insulation, flooring and foundations. The options investigated are listed below.

- **Wall types** investigated include: Hempcrete, Timber frame, Steel frame, Straw bale (infill), Structural Insulated Panels (SIPS) and Timber frame reverse brick veneer
- **External cladding** (for timber frame) of local hardwood timber and fibre cement panels
- **Window** frames and glazing options included aluminium (with thermal break on double glazed option), timber, and uPVC frames. Glazing options included single, double, and low-E.
- **Ceiling insulation** batt options investigated include: Hemp, Wool, Recycled Denim (Cotton), Fibreglass, Rockwool (Mineral Wool), Polyester and Rigid Polystyrene.
- **Flooring** options investigated for the living areas (lounge, dining, kitchen) and bedrooms include: Polished Concrete (Slab), Marmoleum/Linoleum, Cork, 19mm

[1] Note that the shared battery storage system has been excluded from the scope of this study but may be included in LCA studies of the development.

Timber (Local Hardwood directly glued to concrete slab), Rammed Earth (Locally Sourced) and Wool carpet (in the bedrooms only).

- **Foundation** options investigated included Extended (eco) concrete (30% fly ash blend) and Insulated slab edges (R1.5 XPS).

The architectural drawings of the Cottage Lot design (supplied by the Ecovillage project team) were first used to assess the thermal performance of the Base Case Design and each of the Design Options. Thermal modelling of the Base Case Design and various Design Options were assessed by ESD Australia using BERS Pro V4.3.0.X (3.13).

Secondly, the architectural drawings were used to develop detailed lists of materials that were entered into the eToolLCD building LCA software. Further life cycle inventory details for each Design Option were researched and documented throughout the study to ensure transparency and validity of the results. LCA modelling was conducted by Andrew D Moore (Certified LCA Practitioner) using eToolLCD LCA software and the Australasian Life Cycle Inventory Database (v13) provide by Life Cycle Strategies. For the Base Case Design and each of the Design Options, the full life cycle was assessed including raw material extraction, processing, manufacturing, transport, operational energy & water use, maintenance, replacements, and disposal at the end-of-life.

The functional unit of the study was “the whole building over the predicted service life of 80 years (study period of LCA)”. The period of the study was 2019.

The study includes for seven potential environmental impact indicators: Global warming potential (GWP), Acidification potential (AP), Eutrophication potential (EP), Photochemical ozone creation potential (POCP), Ozone depletion potential (ODP), Depletion potential of abiotic resources -Elements (ADPE) and Depletion potential of abiotic resources – Fossil fuels (ADPF).

The background LCA model and the report have been critically reviewed by Fei Ngeow (LCA practitioner eToolLCD) and Richard Haynes (eTool Pty Ltd co-CEO) to ensure that the study was scientifically rigorous and is in compliance with the LCA standards.

RESULTS AND INTERPRETATION

Results are presented for the Base Case Design and all design options focussing on Global Warming Potential (GWP) – also referred to as the carbon footprint. The results for the other environmental impact indicators are also presented in the body of the report to identify hotspots and minimise potential burden shifting between environmental impact indicators.

Base Case Design with and without solar PV

The Base Case Design without a solar PV system would have a carbon footprint of 566,000 kg CO_2e, which includes emissions associated with the materials and energy, over the 80-year predicted service life of the dwelling. Installing a 6.6 kWp solar PV system, with no other changes, would result in a net negative carbon footprint (-47,800 kg CO_2e) over the life of the building[2]. The study demonstrated that the use of solar PV is the single most effective way to reduce the carbon footprint of the dwelling. However, the use of solar PV does produce higher Depletion potential of abiotic resources -Elements (ADPE). These impacts can be further reduced by:

- Ensuring that rare and valuable substances are recycled at the end-of-life.
- Choosing inverters that have a long product life.
- Requesting life cycle information from equipment manufacturers to ensure that they are aware of – and actively taking steps to reduce – the environmental impacts of the products that they produce.

When interpreting the results, it is important to keep in mind that the base case scenario - against which the different design options are compared - already includes a 6.6 kW solar PV system (as this is a requirement for all dwellings in the village). This means that:

- **Results are negative (e.g. the carbon footprint of the base case design is -47,800 kg CO2e over the study period). The design options with the lowest values have lower impacts for each impact category.**
- **Percentage difference in results compared to the base case scenario are larger than they would be if the base case scenario was a typical dwelling that didn't use solar PV and instead consumed electricity from the grid.**
- **The results of this study only valid for the scope as outlined within this report and may not be indicative of or applicable to other circumstances.**

Hotspots in the Base Case Design

Hotspot analysis of the Base Case Design indicated that the use of high-efficiency air-conditioning, appliances and equipment (including refrigerators, freezers, televisions, dishwasher, washing machine, clothes dryer, computers, rainwater pumps and UV sterilisers) can significantly affect the environmental impact indicator results of the building. The majority of the GWP impact associated with the hotspot items can be addressed through the use of solar electricity which supports the focus of the design team. However, the consumption of electricity, whether from onsite solar or the grid, reduces the net benefit from electricity exported as exported solar electricity displaces electricity that would

[2] Compared to electricity supplied from the grid (WA SWIS). See Electricity grid mix section for details.

otherwise be produced from fossil fuels. Therefore, it is important to use appliances and equipment that are as energy-efficient as possible, to minimise electricity consumption, in addition to the use of solar PV systems.

Design Options – Wall types

The results for all wall Design Options were significant improvements over the Base Case Design with GWP reductions of between -98% to -141% (Figure 1).

Further investigation of additional scenarios for wall types revealed that the wall types with the lowest GWP was Strawbale infill with clay render and internal mud-brick walls (-187% compared to the Base Case Design) and Timber frame with reverse mud-brick veneer and mud-brick internal walls (-178% compared to the Base Case Design). All wall types benefited from increased thermal mass inside the building envelope. The relative results for the other environmental impact categories show reductions compared to the Base Case Design and do not indicate any significant burden shifting between environmental impact categories.

The GWP hotspots in the Hempcrete wall system are the production of the lime and the assumption that lime and hemp shiv are transported from Europe. The sensitivity analysis on the transport demonstrated that if the hemp and lime could be produced locally the GWP of the hempcrete wall system could be reduced by 11% on whole-building basis.

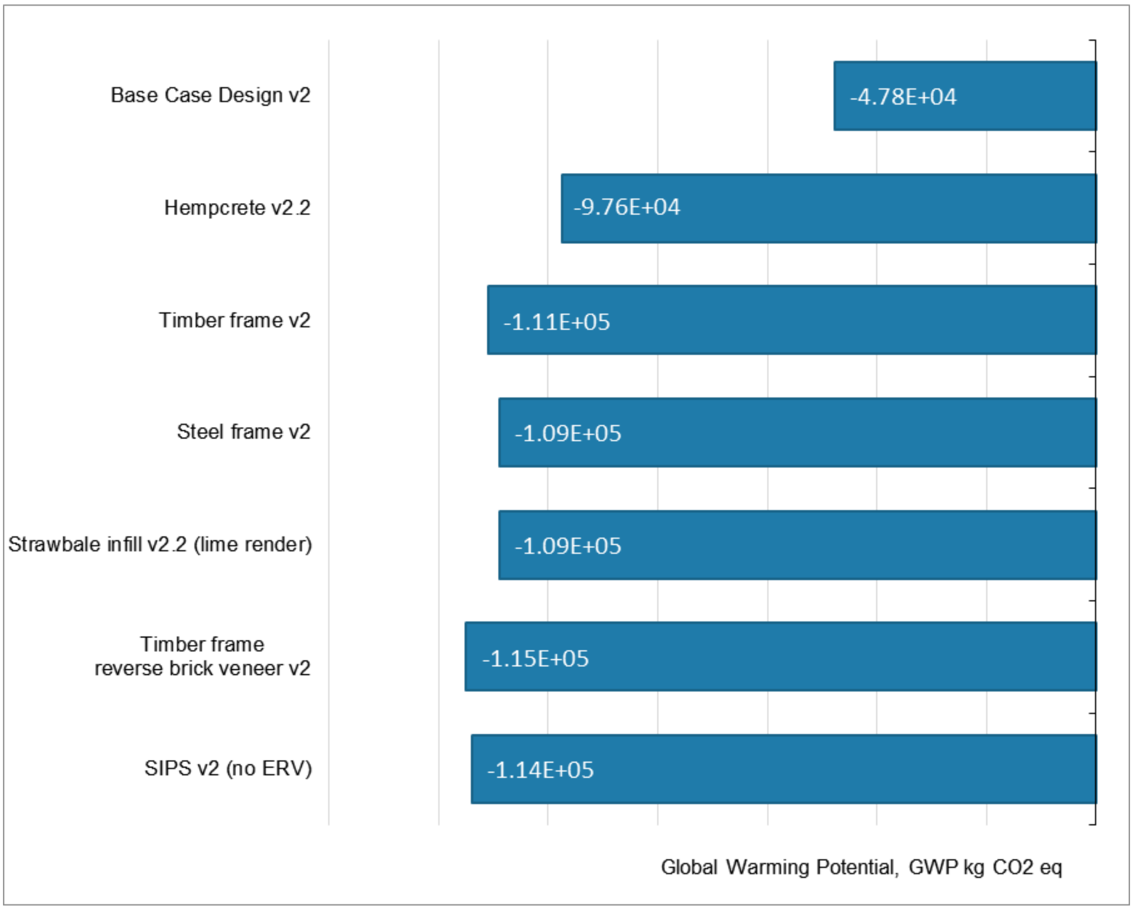

Figure 1 Global warming potential results for Base Case Design and Design Options for external walls (default assumptions)

Design Options – External cladding

The results comparing the use of fibre cement external cladding with timber cladding are compared, assuming Timber frame wall construction. The results indicate that the use of fibre cement cladding leads to a small increase in GWP by 6% over the life cycle of the dwelling compared to timber cladding. The results for the other environmental indicators do not change significantly.

Design Options – Windows

Both the Timber and uPVC double glazed windows have the lowest GWP results (-33%) followed by aluminium double-glazed windows (~-14%).

Design Options – Ceiling insulation

The results for all ceiling insulation types were all very similar except for the results for wool insulation which was significantly higher. The GWP results for wool are dominated by the enteric methane emissions from the sheep (Wiedemann et al. 2016).

Design Options – Flooring

The GWP results for the choice of flooring in the living areas indicate that the Marmoleum/Linoleum and Timber have similar results with a 7% reduction compared to the

Base Case Design which assumed the use of floor tiles. Rammed earth floors gave a 5% reduction and there was little difference between whether the earth floor was installed on top of the concrete slab or directly onto a rock and sand base. Timber flooring in the bedrooms reduced the GWP by 14% compared to nylon carpet (the Base Case Design assumption) whereas wool resulted in significantly higher emissions (+52%).

Design Options – Foundations

The use of extended (eco) concrete (30% fly ash blend) reduced the GWP slightly (-3%); however, insulated slab edges lead to slightly higher impacts (GWP +3%) over the life cycle compared to the Base Case Design.

Design Options – Rainwater tanks

Additional scenarios that were investigated for rainwater tanks showed that reducing the rainwater consumption from 122 to 100 L/person/day can lead to significant reductions in GWP (-24%) through a combination of reduced electricity consumption of the pressure pump and reduction in tank size required. Higher tank life (40 years compared to 20 years) also can significantly reduce the GWP of the building (-14%).

CONCLUSIONS AND RECOMMENDATIONS

Maximise the electricity production of solar PV

- It is recommended that the roof orientation of buildings and tree placement (to minimise shade) are planned to optimise the output of solar systems across the development[3].

Recommend the use of high-efficiency appliances and equipment

- It is recommended that homeowners be informed of the importance of using high-efficiency air-conditioning systems, appliances[4] and equipment.

Recommend the use of external wall types with high insulation values and internal walls with high thermal mass

The conclusions from the assessment of wall Design Options are:

- Increasing the internal thermal mass of all Design Options through the use of clay brick (or even lightweight brick) lead to better thermal performance and lower greenhouse gas emissions over the life cycle of the building.

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[3] The ideal arrangement of solar modules for the development may be different from simply facing due north at an angle equal to the latitude. To optimise production across the day a combination of east, north, and west facing modules may be required. Further investigation of building roof orientation may be required.

[4] Appliances include all built-in appliance and plug loads: refrigerators, freezers, televisions, dishwasher, washing machine, clothes dryer, computers, rainwater pumps and UV sterilisers.

- The use of ERV units in SIPS buildings does result in a slightly higher carbon footprint (compared to a SIPs building without an ERV unit) due to electricity consumption. Due to the airtight nature of many of the wall types, ERV units may need to be considered to ensure adequate ventilation. Where used, ERVs should be controlled using automatic occupancy sensors (e.g. carbon dioxide sensors) to reduce electricity consumption as much as possible.

Recommend the use of timber external cladding

- The use of fibre cement external cladding increased the GWP by 6% compared to a Timber frame wall with timber cladding; therefore timber cladding should be used where possible to reduce the carbon footprint of the building further.

Recommend the use of double-glazed windows where suitable

- The LCA results for windows were lowest for the double-glazed timber and uPVC windows.
- This study assumes that all windows in the dwelling are of the same type; however, conducting thermal modelling of each proposed dwelling will enable further cost and thermal performance optimisation of specific glazing combinations.

Recommend well-insulated ceilings (but avoid the use of wool insulation)

- The LCA results demonstrated the benefits of using high levels of ceiling insulation than the BCA minimum requirement.
- The GWP results for the wool insulation were significantly higher than other ceiling insulation types that were investigated. These results were cross-checked with several peer-reviewed studies which confirmed high GWP values for wool were due to the enteric methane emissions from the animal's digestive systems.

Recommend the use of Timber, Marmoleum, or Earth flooring

- The LCA results were lowest for local solid timber flooring, Marmoleum/linoleum or earth flooring.
- The results for polished concrete (grind and seal) were similar for tile floors.
- The results for earth flooring were similar whether the flooring was on top of the slab or a rock/sand base due to the additional concrete required for extra wall foundations.
- The wool carpet had higher GWP due to the enteric emissions from the sheep digestive systems.

Recommend the use of local supplementary cementitious materials in slab foundations

- The use of fly ash in the foundations lead to a slight reduction in the GWP of the building.
- The use of insulated slab edges increased the GWP over the life of the building so are not recommended for this building design.

Recommend the use of water-saving initiatives to reduce the carbon footprint of the dwelling

- The LCA results demonstrated that by reducing the water consumption from 122 to 100 L/person/day could produce significant reductions in GWP (-24%). These reductions are achieved by reducing the electricity consumption of the water pump, reducing the size of the rainwater tanks required, and by reducing the GWP of the wastewater treatment plant.

Recommendations for further research

- The study highlights the importance of thermal modelling and LCA to select the most appropriate materials for the specific building design. It is recommended that further research is conducted for each design to optimise environmental performance over the entire life cycle.
- This LCA study was developed to enable valid comparison between design options and some design elements have been excluded (e.g. fixtures and fittings) as they are common to all designs, therefore, the inclusion/exclusion have no impact on the results. It is recommended to expand the scope of the study to include these elements into the building LCA models before making any claims of the carbon neutrality of the Cottage Lot design.
- Alternative wall construction methods including; mud/earth brick and light earth, could also be investigated.
- The additional building material templates that have been produced as part of this study could be added to the eToolLCD database to facilitate the development of a streamlined building LCA process that could be used to rapidly and cost-effectively assess the life cycle of each building design to suggest further improvement options.
- Life cycle assessment could be used to assess each aspect of the Witchcliffe Ecovillage to identify additional areas of improvement and to quantify the carbon footprint of the whole development.

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ABBREVIATIONS

ADP	Abiotic depletion potential, fossil fuels
ADPE	Abiotic depletion potential for non-fossil resources (elements, ADPE)
ADPF	Abiotic depletion potential for fossil resources (fossil, ADPF)
AIRAH	Australian Institute of Refrigeration, Air conditioning and Heating
AP	Acidification potential (of land and water)
AU	Australia (ISO country code)
AusLCI	Australian Life Cycle Database Initiative
ALCAS	Australian Life Cycle Assessment Society
CFC	Chlorofluorocarbons
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Coefficient of performance (a measure of efficiency)
EN	European Norms
EP	Eutrophication potential
GHG	Greenhouse Gas
GIA	Gross internal area
GJ	Gigajoule
GWP	Global Warming Potential
HVAC	Heating, ventilation, and air conditioning
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standard Organization
kg	Kilogram
kWh	Kilowatt-hour
L	Litre (kL: kilolitre)
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment
LED	Light-emitting diode
m^2	One square metre
m^3	One cubic metre
MJ	Megajoule
ML	Megalitre
MW	Megawatt
MWh	Megawatt-hour
ODP	Ozone depletion potential
POCP	Photochemical ozone creation (POCP)
R-value	The thermal resistance rating (m^2K/W)
SAM	United States National Renewable Energy Laboratory System Advisor Model
SHGC	Solar Heat Gain Co-efficient (Watts)
U-value or Uw	Uw is a measure of the conductivity of the whole window (glass and frame included)
WA	Western Australia
WEV	Witchcliffe Ecovillage

1 INTRODUCTION

Sustainable Settlements Pty Ltd commissioned Life Cycle Logic to conduct a Life Cycle Assessment (LCA) study to inform the development of the Design Guidelines for the Witchcliffe Ecovillage. The study aimed to conduct an LCA on a Base Case building design which would act as a benchmark against which a range of Design Options would be compared.

1.1 WITCHCLIFFE ECOVILLAGE

The Witchcliffe Ecovillage is a sustainable community that will be located 10 km south of Margaret River in Western Australia. The vision for the Ecovillage is:

> To create a model of a highly sustainable, self-reliant community in a regional village setting, incorporating the best of 21st century technology and human settlement design to enable the Ecovillage community to produce as much energy as it consumes; be self-sufficient in water; care for the local environment; generate ongoing economic and social opportunities for the area; be socially diverse; and be self-sufficient in fresh food produce (Witchcliffe Ecovillage 2017).

The Sustainable Settlements Pty Ltd project team describes the ecovillage as being designed with an extensive range of onsite infrastructure and services to create an example of sustainable development that achieves (Witchcliffe Ecovillage 2017):

- 100% renewable power generation on site.
- 100% self -sufficiency in water through onsite rainwater harvesting (rainwater tanks and dams).
- All infrastructure required to enable self-sufficiency in seasonal fresh foods provided by the developer.
- A local micro energy grid that utilises smart grid technology.
- All wastewater recycled on-site.
- Highly efficient solar passive homes that all front public open space and/or community gardens.
- Many sustainable employment, small business and education opportunities within the ecovillage.
- Revegetation and protection of remnant vegetation and creek lines to create wildlife corridors.
- Extensive shared path network to encourage and prioritise pedestrians and bikes.
- NBN fibre to each home and business provided.

1.2 DESIGN GUIDELINES

A set of building Design Guidelines are being developed for the Ecovillage to ensure that the built form and landscaping of the Ecovillage reflects the strong vision of sustainability and the clear character set for the development. They will provide straightforward guidelines that will apply to all residential and commercial buildings in the Ecovillage. They will help owners, designers and builders create aesthetically harmonious buildings which are passive solar, efficient, affordable, and comfortable to live and work in (Sustainable Settlements 2019).

1.3 LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a methodology to quantify environmental impacts of a product over its whole life, cradle-to-grave. Quantifying different environmental impacts over the whole life cycle leads to a greater understanding of what the impacts are, where impacts occur in the life cycle, and how the sustainability improvements can be made.

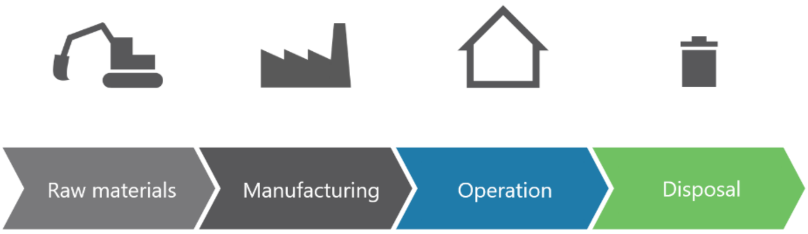

Figure 2 Phases considered in life cycle assessment studies of buildings

LCA studies can focus on specific phases (cradle to gate or gate to gate) or include the whole life cycle from cradle-to-grave. Typical life cycle phases of buildings include raw material extraction, manufacturing of building materials, operation of the building, and disposal at the end of life.

LCA studies generally look at many different environmental impacts including global warming (carbon footprint), acidification (acid rain), eutrophication (nutrient pollution), resource depletion, water use, and photochemical oxidant creation potential (summer smog). There are international and national standards for life cycle assessment which ensure that studies are conducted in a robust and consistent way.

1.4 STANDARDS

This study has been conducted following the international standards for LCA:

- ISO 14040:(2006a) - Environmental Management - Life Cycle Assessment - Principles and Framework'. International Standard Organization (ISO), Genève, Switzerland

- ISO 14044:(2006b) Environmental Management — Life Cycle Assessment — Requirements and Guidelines'. International Standard Organization (ISO), Genève, Switzerland
- EN 15978:(2011) – Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method

An independent third party critically reviewed the study to ensure it followed the abovementioned standards. The review process was conducted following:

- ISO 14071:(2014) Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

2 GOAL AND SCOPE

The goal and scope are based on discussions that were held with Jeff Thierfelder, Mike Hulme and Michelle Sheridan of Sustainable Settlements Pty Ltd between June 2019 and October 2019.

The scope of the project was initially defined on the 10th of June 2019. After a presentation of initial results of the study to the project team on the 15th of August 2019, and discussions with Mike Hulme on the 22nd August 2019 (in person and over the phone), the scope was revised and expanded as described below.

1.5 REASONS FOR CARRYING OUT THE STUDY

The primary reason for carrying out the study is to:

- Conduct a life cycle assessment study of the Witchcliffe Ecovillage- Passive Solar Cottage Lot Base Case Design to act as a "business-as-usual" scenario (the Base Case Design) against which other Design Options can be compared. The results of the study are intended to inform the development of the Witchcliffe Ecovillage Design Guidelines.

Other reasons for carrying out the study are:

- To provide background technical information that was used in the development of the Design Guidelines.

1.6 INTENDED APPLICATIONS

Conducting an LCA study is an essential step for Sustainable Settlements Pty Ltd to understand and quantify the environmental impacts associated with its building designs.

The intended applications for the study are:

- To inform the development of the Witchcliffe Ecovillage Design Guidelines.

The results of the study are not intended to be the basis of comparative assertions or environmental claim regarding the superiority or equivalence of products.

1.7 TARGET AUDIENCE

The target audience for the LCA report are:

- Sustainable Settlements project team
- Members of the building industry
- General public

1.8 SCOPE – COTTAGE LOT PASSIVE SOLAR DESIGN

The Witchcliffe Ecovillage Cottage Lot Passive Solar Base Case Design is the benchmark against which alternative Design Options in the study are compared.

The Base Case Design is a 161 m^2 (including exterior walls) three-bedroom, two-bathroom passive solar home. The walls on the Base Case Design are double brick and are laid on a typical on-grade concrete slab with footings.

The Cottage Lot Base Case Design is designed for one to three people. The sizing of the rainwater and solar systems are based on accommodating three people full time.

The floor areas for the different functions are presented below in Table 1.

Table 1 Floor areas for the different functional zones

Item	Area (m^2)
House (including exterior walls)	161
Carport	36
Porch	6.1
Solar pergola	26.6
Store/drying area	18

The floor plan of the Cottage Lot Base Case Design that has been assessed is presented in Figure 3.

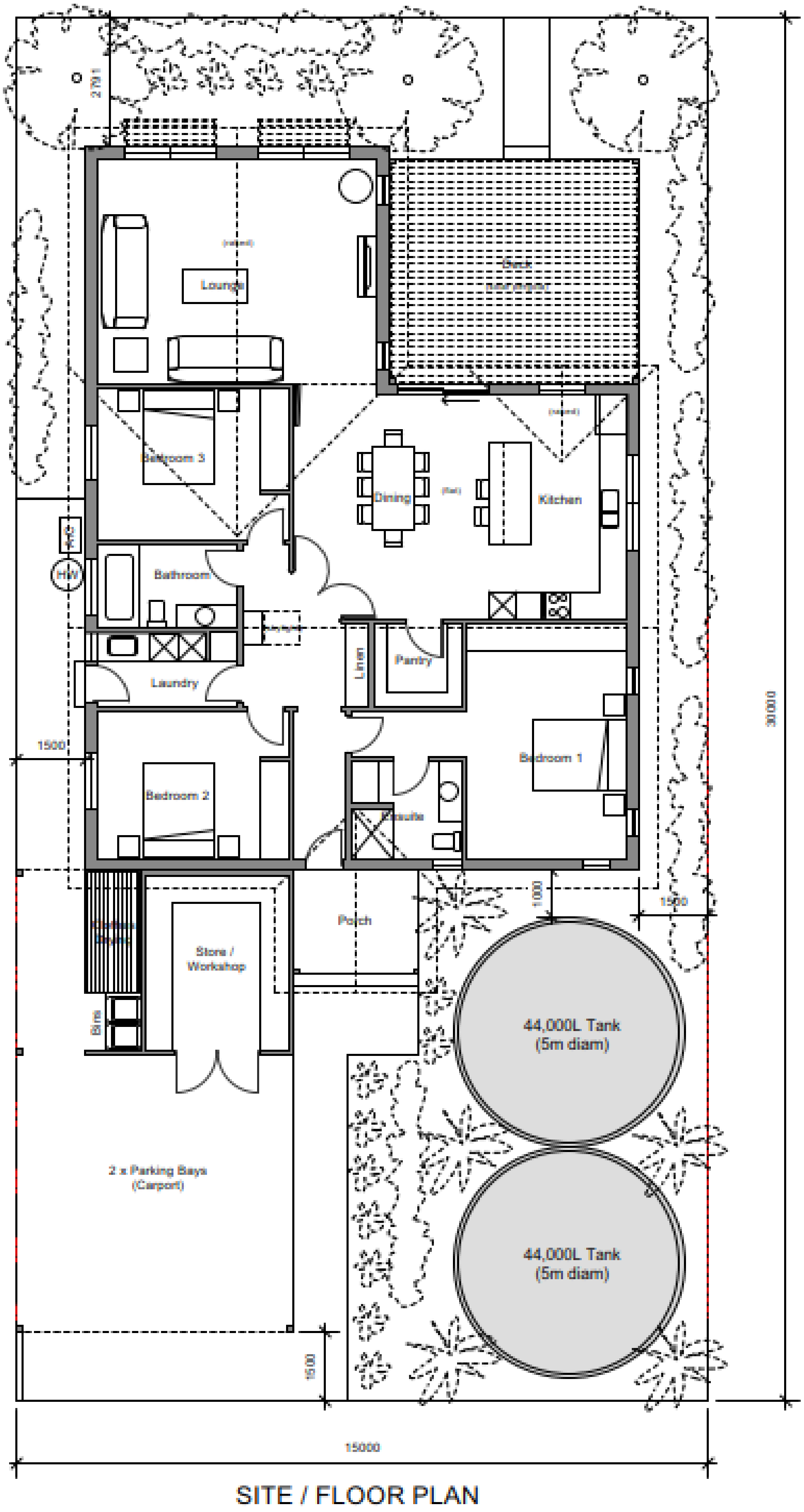

Figure 3 Floor plans of the Cottage Lot Passive Solar House (Thierfelder 2019)

The key sustainability features included in the Cottage Lot Base Case design are:

- Passive solar design and passive solar lot orientation
- 6.6 kWp photovoltaic (PV) solar system, (with shared battery storage[5])
- Rainwater storage tanks with pressure pump and ultraviolet water treatment system (there is no mains/scheme water connection)
- Heat pump hot water system

1.8.1 Base Case design

The scope of the Base Case design, against which design options will be compared, include:

- Cavity-brick construction
- Sand render exterior finish
- Slab on grade foundation
- Colorbond roofing
- Single glazed standard aluminium windows
- Rockwool ceiling insulation (R6.0)
- Synthetic carpets in bedrooms
- Tiles in living spaces
- Tiles in wet areas
- Standard wet plaster and conventional paint on interior

The modelling assumptions for each of these design elements are documented in detail in section 2 Life Cycle Inventory.

Other design elements that have been included in the design to provide relevant context to the results include:

- Timber roof framing with gutters, downpipes, soffits, eaves, and paint
- Plasterboard ceilings
- Timber deck
- Exterior and interior doors
- Storage room masonry walls (single brick with concrete render)
- Timber posts
- Timber shade structures
- Timber solar pergola
- LED lighting

[5] Note that the shared battery storage system has been excluded from the scope of this study but may be included in LCA studies of the development.

- Refrigerator(s) and freezer
- Heat pump hot water system (315 L, high COP, CO_2 refrigerant)
- Sewage connection and wastewater treatment (at a municipal wastewater treatment plant)
- Reverse cycle air-conditioning system for the living space (kitchen, dining and lounge)
- Ceiling fans in the bedrooms
- High-efficiency appliances (televisions, dishwasher, washing machine, clothes dryer, computers, miscellaneous)
- 6.6 kWp photovoltaic (PV) solar system
- Two 44 kL rainwater storage tanks with pressure pump and ultraviolet (UV) water treatment system

Note that the study excludes some fixtures and fittings that are common between the Base Case Design and the Design Options investigated as they have no direct influence on the comparative results (e.g. basins, sinks, taps, spouts, toilets, cupboards, benchtops, furniture).

1.8.2 Design Options

The study includes several building element design options and scenarios as listed below. For further details on each design option, please refer to section 2 Life Cycle Inventory.

1.8.2.1 Wall Structures

The external wall structures investigated for the study are described below. The thermal resistance ratings of the complete wall systems are presented below in Table 2.

Hempcrete - 330mm hempcrete (imported from Europe) with timber structure and external and internal lime render. An additional scenario has been included for locally produced hemp shiv and lime.

Timber Frame - 90mm timber frame, vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape), R3.0 recycled poly batt insulation (80% recycled), 25x45mm timber battens, hardwood cladding, plasterboard.

Steel Frame - 90mm steel frame (steel C channel type: tracks for top plate & bottom plate, studs and noggins), vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape), R3.0 recycled poly batt insulation (80% recycled), hardwood cladding, plasterboard

Straw Bale (infill) - 450mm straw bale with a timber structure and lime render internal and external. A second scenario also includes the use of clay render (which is free from lime or cement).

SIPS - 175mm SIPs panels, vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape, 25x45mm timber battens, hardwood cladding, plasterboard. Due to the airtight nature of the SIPS building system, a scenario has been included with the operational energy consumption of an Energy Recovery Ventilator (ERV).

Timber frame reverse brick veneer (lightweight brick) - 90mm timber frame, vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape), R3 fibreglass batt insulation, 25x45mm timber battens, hardwood cladding, single leaf internal lightweight/fast brick (305 x 90 x 162mm, 5.15kg ea.), wet plaster. An additional scenario includes mudbrick with clay render for the brick veneer.

Table 2 R-values of the wall structures

Item	Wall system R-value (m2.K/W)
Base Case Design (double cavity brick)	R 0.46
Base Case Design (with R1.3 cavity insulation)	R 1.76
Hempcrete	R 4.10
Timber frame	R 3.08
Steel frame	R 3.08
Strawbale infill[6]	R 4.54
SIPS	R 4.49
Timber frame reverse brick veneer	R 3.17

1.8.2.2 External Cladding

The external cladding options assessed include:

- Locally Sourced Hardwood Weatherboard Cladding

[6] The R-value of the 450mm Strawbale infill wall in the BERS Pro V4.3.0.X (3.13) software is R4.54, with conductivity value of 0.0990 W/m^2.K and C-value of 56.25 kJ/m^2.K (Energy Inspection 2019). This figure has been cross checked against other peer reviewed literature sources: Stone (2003) presented results from a range of thermal tests of complete Strawbale wall systems and concluded that the a typical thermal performance was Imperial R1.45 per inch, which, converted to metric R-value for a 450mm bale is R4.52 (450mm bale width/254 mm/inch * $R_{imperial}$ 1.45/inch *0.1761 $R_{metric}/R_{imperial}$ = metric R-value 4.52).

- Fibre Cement Panels

1.8.2.3 Window frames and glazing

The window frame and glazing Design Options included in the study are listed in Table 3.

Table 3 Window frames, glazing and performance values assessed

Window frame	Window glazing	Performance Values	
		Sliding/Fixed	Awning
Aluminium (no thermal break)	Single glazing	U-Value - 6.7 SHGC - 0.7	U-Value - 6.7 SHGC – 0.57
Aluminium (no thermal break)	6mm Single Glazed Low-E	U-Value – 5.4 SHGC - 0.58	U-Value – 5.4 SHGC - 0.49
Aluminium (no thermal break)	Double glazed	U-Value – 4.8 SHGC - 0.59	U-Value – 4.8 SHGC - 0.51
Timber	Single glazing	U-Value – 5.4 SHGC - 0.63	U-Value – 5.4 SHGC - 0.56
Timber	6mm Single Glazed Low-E	U-Value – 4.3 SHGC - 0.5	U-Value – 4.3 SHGC - 0.42
Timber	Double glazed	U-Value – 3.0 SHGC - 0.56	U-Value – 3.0 SHGC - 0.48
uPVC	Single glazing	U-Value – 5.4 SHGC - 0.63	U-Value – 5.4 SHGC - 0.56
uPVC	6mm Single Glazed Low-E	U-Value – 4.3 SHGC - 0.50	U-Value – 4.3 SHGC - 0.42
uPVC	Double glazed	U-Value – 3.0 SHGC - 0.56	U-Value – 3.0 SHGC - 0.48
Aluminium (thermal break)	Double glazed	U-Value – 3.6 SHGC - 0.54	U-Value – 3.6 SHGC - 0.47

1.8.2.4 Ceiling Insulation

The R6.0 roof ceiling insulation Design Options in the study include:

- Hemp batts
- Wool batts
- Recycled Denim (Cotton)
- Fibreglass batts
- Mineral Wool batts
- Polyester batts
- Rigid Polystyrene

1.8.2.5 Flooring – living areas

The flooring Design Options for the living areas (lounge, dining, and kitchen), in addition to tile flooring in the base case design) include:

- Polished Concrete (Slab)
- Marmoleum / Linoleum
- Cork
- 19mm Timber (Local Hardwood directly glued to concrete slab)
- Rammed Earth (both including and excluding slab foundation)

1.8.2.6 Flooring – bedrooms

The flooring Design Options that were assessed for the bedrooms (in addition to the nylon carpet base case option) include:

- Wool Carpet
- 19mm Timber (Local Hardwood directly glued to concrete slab)

1.8.2.7 Foundations

Two additional Design Options were investigated for the building foundations:

- Slab on Grade using Extended (Eco) Concrete
- Insulated slab edges, R1.5, rigid extruded polystyrene (XPS) edge insulation

1.8.2.8 Additional design option scenarios

Several additional scenarios were included to model:

- Reductions in water use (122 to 100 L/person/day)
- Increasing the life of the rainwater tank and liner (20 to 40 years)
- The use of average appliances rather than high-efficiency appliances

Refer to section 2.2.2 for details of the modelling assumptions.

1.9 FUNCTIONAL UNIT

The functional unit of the study is the whole dwelling over the 80-year reference study period.

Alternative functional units may be used in future revisions of the study where comparisons with other building designs (on different lot sizes) may be made (e.g. m^2 of gross floor area, number of occupants, or number of bedrooms.

1.10SERVICE LIFE

The service life of the whole building and the service life of individual components and construction materials are taken into account to calculate the environmental impacts. There are several aspects to the service life as defined below.

1.10.1 Reference study period

The reference study period is the time over which the life cycle of the building is assessed. The reference study period is set to the ‘predicted service life’ of the dwelling, which was calculated to be 80 years.

The predicted service life was calculated using the eToolLCD software (Richard Haynes 2019) which takes into consideration the structural service life limit (100 years), as well as redevelopment pressure on the asset such as surrounding density, asset ownership structures, and the architectural design quality.

Note that products with expected service lives of less than the life span of the project are assumed to be replaced at increments reflecting their service life.

1.10.2 Reference service life

The reference service life (RSL) of each of the building components is defined in order to calculate the maintenance, replacement and refurbishment impacts. The RSL for each product is specified in the separate detailed life cycle inventory tables documents (see section 7: APPENDIX B - DETAILED LCI TABLES for further details).

1.11SYSTEM DIAGRAM

The object of the assessment is the Cottage Lot passive solar dwelling. The assessment includes all the upstream and downstream processes needed to provide the primary function of the structure from construction, maintenance, operation and disposal. The inventory includes the extraction of raw materials or energy and the release of substances back to the environment or to the point where inventory items exit the system boundary either during or at the end of the project life cycle.

The LCA of the building includes all stages of the life cycle (see Figure 5) from “cradle to grave”. All stages of the life cycle have been included in the LCA according to the LCA building standard EN 15978 (EN 2011).

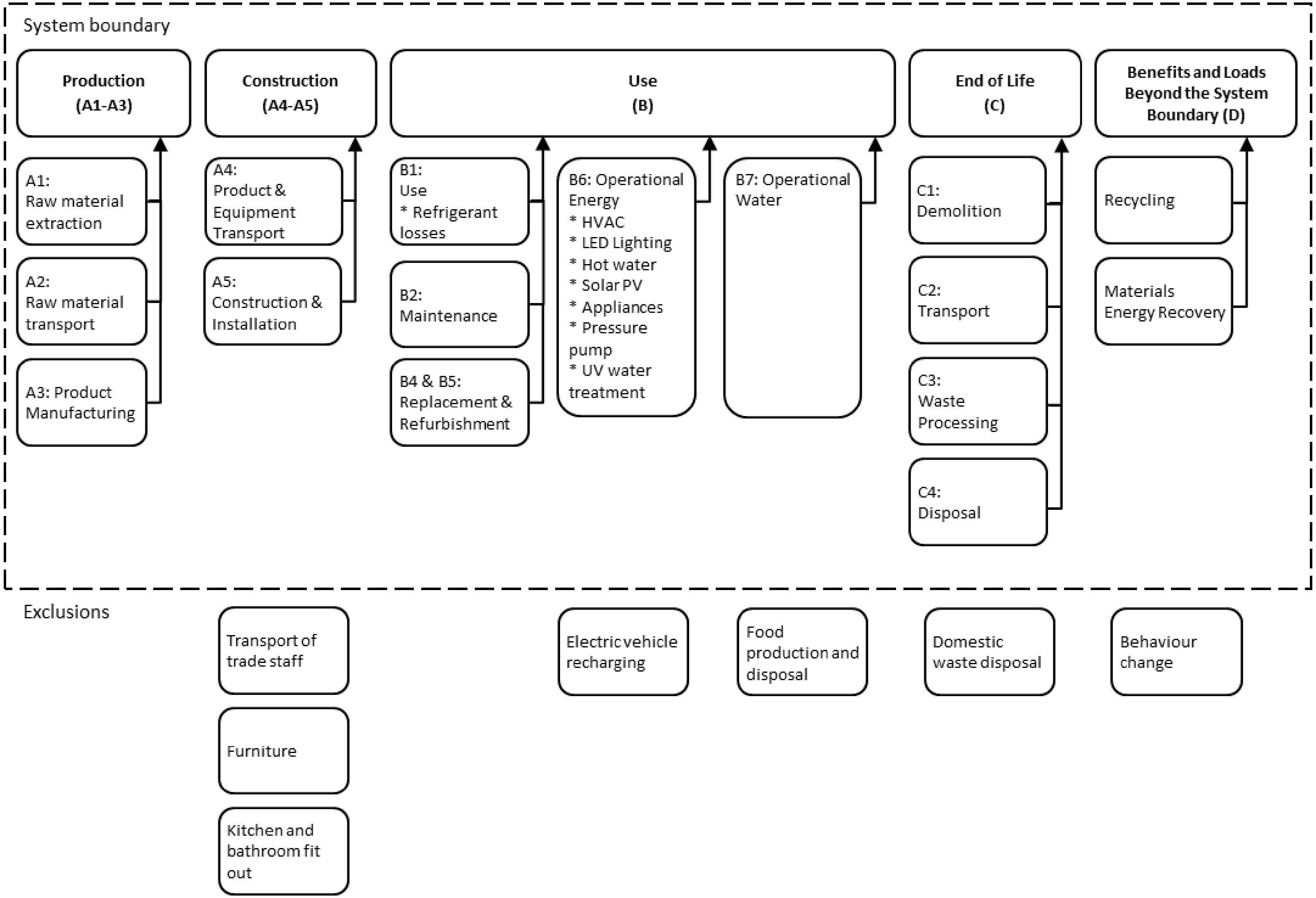

Figure 4 System diagram of the building life cycle (dashed line indicates the system boundary of the study)

1.12 SYSTEM BOUNDARIES

The system boundaries of the study, as per the life cycle standard for buildings EN15978 (2011), are defined below in Figure 5. Following the standard, those stages included in the study are indicated with an ‘X’ at the bottom of the figure.

The study includes all stages of the building life cycle including production, construction, use, end-of-life and benefits beyond the system boundary (e.g. credits for recycling).

Production stage			Construction stage		Use stage							End-of-life stage				Benefits beyond system boundary
Raw material Supply	Transport	Manufacturing	Construction transport	Construction installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction/demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-Potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 5 Building life cycle system boundaries as per EN 15978 (2011) and 15804 (2013)

1.12.1 Geographic coverage

The cottage lot base case design will be located in Witchcliffe, Western Australia. Australian background life cycle data has been used to represent the environmental profile of each of the building materials. Further documentation is provided in the life cycle inventory section.

Transports of building materials throughout the life cycle have been included and modelled using representative Australian and international transport background life cycle data. Refer to section 1.14.1 General assumptions and the detailed inventory in Appendix A for further details.

Provision of energy (solar electricity) and water (100% rainwater) for the building have been specifically modelled using background datasets that are representative of the geographic location. Further documentation is provided in the life cycle inventory section of the report.

1.12.2 Time period

The building is modelled based on a 2019 time period. Construction of the Witchcliffe Ecovillage is scheduled to commence in 2019 (Witchcliffe Ecovillage 2017), although there are no specific plans to build this specific Cottage Lot Passive Solar Design.

1.12.3 Technological coverage

Background life cycle inventory data are selected based on their representativeness of the current state of technology utilised in the building construction.

1.13 ENVIRONMENTAL IMPACT INDICATORS

1.13.1.1 Environmental impact indicators

The potential environmental impact indicator results that are reported for the building are listed in Table 4. These indicators are mandatory for the assessment of the life cycle of buildings in accordance with EN 15987(2011) and EN 15804+A1(2013). Due to the need to take urgent action to address climate change emphasis has been placed on the Global warming potential results. The results for the other environmental indicators have been used to identify potential environmental hotspots to prevent burden shifting between environmental impact categories.

Characterisation factors used in the software for each impact category are in from CML v4.5 (2015[7]) and are in accordance with EN 15804+A1(2013).

Table 4 Mandatory environmental impact categories

GWP	Global warming potential	Emissions that contribute to climate change (also known as the greenhouse effect). It is measured in kg of CO_2e equivalents over 100 years.
ODP	Ozone depletion potential	The potential impact of emissions of synthetic gases on the ozone layer. It is measured in kg of CFC-11 equivalents.
ACID AP	Acidification potential of land and water	Emissions which increase the acidity of the environment (e.g. acid rain). It is measured in kg of SO_2 equivalents.
EP	Eutrophication potential	The addition of nutrients to water bodies reduces the oxygen levels available to support aquatic life. It is measured in kg of PO_4^{3-} equivalents.

[7] The characterisation factors are stated in the eTool software (Reports, LCA report) as being CML v 4.5 which are the same as CML v4.1. Version 4.5 has additional factors for substances and indicators not included in v4.1. Refer to the version history in the spread sheet in the reference for details.

POCP	Photochemical ozone creation potential	Contribution to air pollution in the form of smog. It is measured in kg of C_2H_4 equivalents.
ADPE	Depletion potential of abiotic resources (elements)	The potential impact of consuming non-renewable elements and mineral resources. It is measured in kg of Antimony (Sb) equivalents.
ADPF	Depletion potential of abiotic resources (fossil)	The potential impact of consuming non-renewable fossil fuel resources. It is measured in MJ net calorific value.

1.14ASSUMPTIONS AND LIMITATIONS

The underlying assumptions and limitations of the study have been documented below and in each section of the report.

1.14.1 General assumptions

Transport

Specific transport details for each material are included in the detailed inventory in appendix A. Note that where more than one transport mode is listed, they are added as multiple transport legs.

Recycling rates

Information on recycling rates for Western Australia have been documented as currently being inadequate (Commonwealth of Australia 2018) – general recycling rates are reported but specific recycling rates for metals are not available. Material recycling rates for Western Australia are included below in Table 5.

Table 5 Waste recycling rate for Western Australia 2014-2015 (Pickin and Randell 2017)

Item	Recycling rate	Reference
Masonry	45%	(Pickin and Randell 2017)
Metals	81%	(Pickin and Randell 2017)
Organics	34%	(Pickin and Randell 2017)
Paper and cardboard	56%	(Pickin and Randell 2017)

Item	Recycling rate	Reference
Plastics	4%	(Pickin and Randell 2017)
Glass	38%	(Pickin and Randell 2017)
Other	24%	(Pickin and Randell 2017)
Construction and demolition	42%	(Pickin and Randell 2017)

The summary of recycling rate assumptions for materials used in the LCA modelling is provided in Table 6. The specific recycling rates used in the LCA modelling for each material are documented in the detailed inventory in appendix A.

Table 6 Summary of recycling rate assumptions for materials

Material	Recycled Content (Manufacturing)	Closed Loop Recycling Rate (End of Life)	Net Flow Recycled Materials (End of Life)	Reference
Steel	40%	80%	40%	(Graedel et al. 2011)
Aluminium	35%	57%	22%	(Graedel et al. 2011)
Copper and brass	29%	48%	19%	(Graedel et al. 2011)
Iron	40%	72%	31%	(Graedel et al. 2011)
Plastics (recyclable[8])	5%	4%	-1%	(Allan 2007; Pickin and Randell 2017)
Zinc	23%	42%	19%	(Graedel et al. 2011)
Glass	0%	38%	38%	(Pickin and Randell 2017)

1.14.1.1 Exclusions

Processes that are excluded from the study, in accordance with the standard EN15978 (2011), are:

- Fitout of the kitchen and bathrooms. (Lighting, and operation of the refrigerator, freezer and other appliances have been included).
- Room furniture (beds, robes, desks, lamps)

[8] Non-recyclable plastics include for example paint and adhesives – refer to the detailed LCI document for specific details.

- Manufacturing of production equipment, other buildings and other capital goods[9]
- Transport of trade staff to and from the building site[10]

Other exclusions are:

- Packaging materials as detailed packaging information not available. The contribution of packaging materials to the results are expected to be below cut-off requirements. Refer to the cut-off criteria section below for further details.

1.14.1.2 General limitations

The study has been conducted for the primary purpose of informing the development of the Witchcliffe Ecovillage Design Guidelines. The results of the study may not be suitable for other purposes (e.g. claims of carbon neutrality).

The results of this study are representative of the Witchcliffe Ecovillage Cottage Lot Passive Solar architectural drawings dated 10/6/2019 and version 2 of the scope revision (28/8/2019). The results may not be representative if the design specifications are altered.

The results of the study are not intended to be the basis of 'comparative assertions' or environmental claim regarding the superiority or equivalence of products.

1.15CUT-OFF CRITERIA

Following the requirements of EN15978 (2011) and EN15804 (2013); life cycle inventory (LCI) data for a minimum of 99% of total inflows to the core processes (construction stage) have been included. An assessment of the cut-off criteria has been provided below for both mass and energy flows to demonstrate compliance with this requirement.

1.15.1 MASS

The cumulative mass of inventory items (specific/primary data) included in the Base Case Design LCA model is shown in Figure 6 below. The items counted include the materials used over the whole life cycle (energy items are included in the following section).

For the Base Case Design, 177 material elements contribute the last 1% of mass inventory entries which demonstrates that there is a high level of confidence that the cut-off requirement for mass has been met.

[9] Note that the background LCA databases include capital goods (infrastructure) for transport datasets which is a deviation from the standards. The effect on the results is considered to have relatively minor significance.

[10] Version 1 of the study did include transport of trade staff to and from the building site. Version 2 of the study has excluded these impacts as most trade staff will live locally.

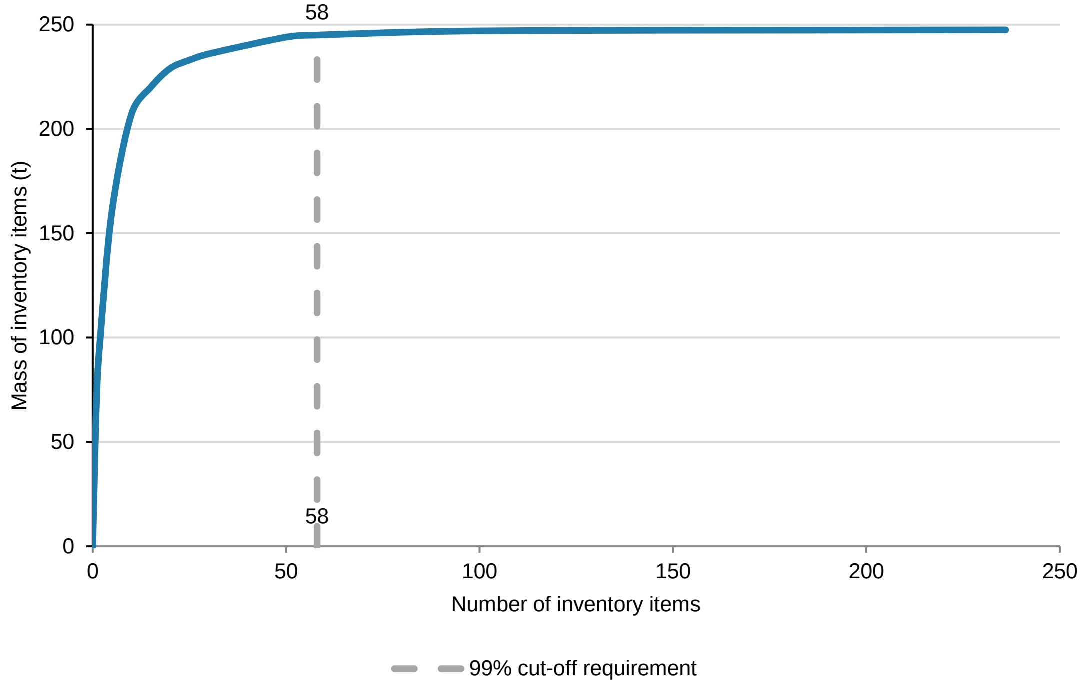

Figure 6 Cumulative mass of inventory items 75% of items make up the last 5% of mass inventory entries).

1.15.2 ENERGY

The cumulative embodied energy of inventory entries is shown in Figure 7. The embodied energy includes all materials and energy items that have no mass (e.g. electricity).

For the Base Case Design there are 347 elements that contribute the last 1% of energy inventory entries there is a high level of confidence that the cut-off requirement for energy have been met.

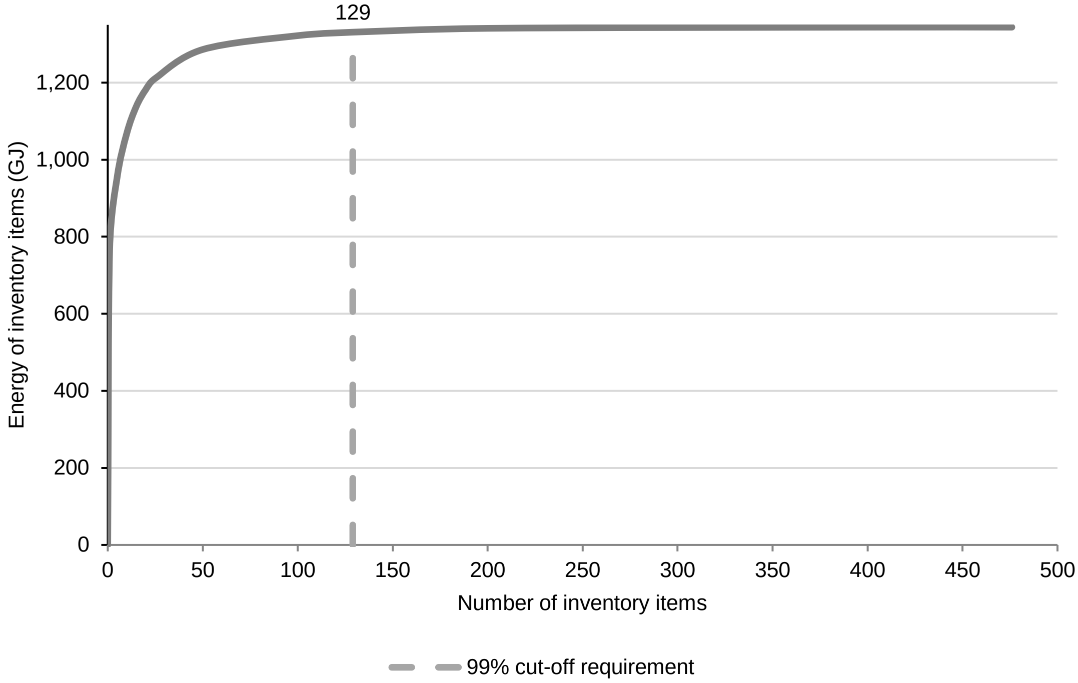

Figure 7 Cumulative energy inventory items (72.7% of items contribute the last 5% of energy inventory entries)

1.16DATA QUALITY ASSESSMENT

1.16.1.1 Time-related coverage

The primary data for the building has been collected from the design documentation. This data includes changes made to the Base Case Design and Design Options in September 2019.

The most up-to-date versions of the background LCI data were used in this study (refer to section 1.16.1.9 Sources of the data for further details).

1.16.1.2 Geographical coverage

Primary data is specific for the Cottage Lot Passive Solar Base Case Design and Design Options to be located in Witchcliffe, Western Australia.

For information on the background LCI data, please refer to section 1.16.1.9 Sources of the data.

1.16.1.3 Technology coverage

Detailed inventory data have been collected specifically for the Cottage Lot Passive Solar Base Case Design and Design Options as specified in the Life Cycle Inventory section of the report.

1.16.1.4 Precision

Primary data for the study has been collected from architectural plans, so they are considered to have high precision.

The operational energy and water data have been calculated using methods documented in the LCI section of the report. The precision of this data is considered to be high.

1.16.1.5 Completeness

The most recent data for specific building design has been collected, and no known flows have been excluded from the LCA modelling, so the completeness of the study is considered to be high.

1.16.1.6 Representativeness

The LCA results are considered to be representative of the latest Base Case design of the building and the Design Options specified.

1.16.1.7 Consistency

The methodology used for the study has been uniformly applied to ensure consistency. The primary data have all been sourced from the building plans or documented sources. Background life cycle data are provided from the same sources. The study consistently follows the method as outlined by the building LCA standards EN15978 and EN15804.

1.16.1.8 Reproducibility

This background report documents the sources of primary data, background LCI data, and methodological choices to ensure the study could be reproducible by other LCA practitioners, as required by ISO 14044 (2006b).

1.16.1.9 Sources of the data

Sources of primary and secondary data used in the study are all referenced to ensure transparency and reproducibility.

Specific data (primary data) has been collected for the building from the following source:

- Architectural and structural plans (which included a material take-off schedule)

Generic data (secondary data) used to model the life cycle of the building has been provided by the eTool Life Cycle Design (eToolLCD) software (Richard Haynes 2019). This online software was explicitly developed to conduct LCA studies on buildings and infrastructure projects. The comprehensive eTool background LCI database is Australasian specific and contains over 300 processes for materials, energy, transport, disposal and recycling.

The background LCI database for materials and energy used by the eToolLCD software is provided by Life Cycle Strategies and is made up of LCI processes form the following sources:

- Australian Life Cycle Database Initiative (AusLCI) (2016), where processes are available
- Ecoinvent Database version 3 (Wernet et al. 2016) shadow database for background flows for the processes in the above data sources.

The most recent and up-to-date versions of the background LCI data sources that are available (Australasian LCI v13 – Life Cycle Strategies) have been used to ensure all data is less than ten years old.

1.16.1.10 Uncertainty of the information

Specific inventory data were collected from the WEV Cottage Lot Base Case Design architectural drawings, and the same background LCI database has been used in the eTool Software to ensure that the uncertainty of the information is low. Data for modelling the operational energy and water are documented within this report and have been cross-checked against several references to reduce any potential uncertainty.

1.17ALLOCATION

The allocation rules follow those of EN15804 (EN 2013) as given below:

- Allocation will respect the main purpose of the studied processes. In cases where the main purpose of combined processes cannot be defined (e.g. combined mining and extraction of nickel and precious metals), economic allocation has been used to divide resources and emissions between the products.
- The principle of modularity has been maintained. Where processes influence the product’s environmental performance during its life cycle, they have been assigned to the module where they occur.
- The sum of the allocated inputs and outputs of a unit process are equal to the inputs and outputs of the unit process before allocation (e.g. there is no double-counting).

1.17.1.1 Co-product allocation

No specific allocations were carried out as part of the modelling of the building. Allocation has been conducted in the eToolLCD software background database by Life Cycle Strategies following the principles of EN15804 (EN 2013) as outlined below:

- Allocation has been avoided as far as possible by dividing the unit process to be allocated into different sub-processes that can be allocated to the co-products and by collecting the input and output data related to these sub-processes.

- Where a process could be sub-divided but respective data are not available, the inputs and outputs of the system under study have been partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.
- In the case of joint co-production, where the processes could not be sub-divided, allocation respected the main purpose of the processes studied, allocating all relevant products and functions appropriately. The purpose of a plant and therefore of the related processes is generally declared in its permit and has been taken into account. Processes generating a very low contribution to the overall revenue may be neglected.
- Joint co-product allocation has been allocated as follows:
  - Allocation has been based on physical properties (e.g. mass, volume) when the difference in revenue from the co-products are low.
  - In all other cases allocation was based on economic values.
  - Material flows carrying specific inherent properties, e.g. energy content, elementary composition were allocated reflecting the physical flows, irrespective of the allocation chosen for the process.

1.18ALLOCATION PROCEDURE OF REUSE, RECYCLING AND RECOVERY

The end-of-life system boundary of the construction product system is set where outputs of the system under study, e.g. materials, products or construction elements, have reached the end-of-waste state. Therefore, waste processing of the material flows (e.g. undergoing recovery or recycling processes) during any module of the product system (e.g. during the production stage, use stage or end-of-life stage) are included up to the system boundary of the respective module as defined above.

Module D declares potential loads and benefits of secondary materials leaving the product system. Module D recognises the “design for reuse, recycling and recovery” concept for buildings by indicating the potential benefits of avoided future use of primary materials and fuels while taking into account the loads associated with the recycling and recovery processes beyond the system boundary.

Where a secondary material or fuel crosses the system boundary, e.g. at the end-of-waste state and if it substitutes another material or fuel in the following product system, the potential benefits or avoided loads can be calculated based on a specified scenario which is consistent with any other scenario for waste processing and is based on current average technology or practice.

A conservative approach has been used in module D to calculate the net impacts as follows:

- Adding all output flows of a secondary material or fuel and subtracting all input flows of this secondary material or fuel from each sub-module first (e.g. B1-B5, C1-C4, etc.), then from the modules (e.g. B, C), and finally from the total product system thus arriving at net output flows of secondary material or fuel from the product system.
- Adding the impacts connected to the recycling or recovery processes from beyond the system boundary (after the end-of-waste state) up to the point of functional equivalence where the secondary material or energy substitutes primary production and subtracting the impacts resulting from the substituted production of the product or substituted generation of energy from primary sources.
- Applying a justified value-correction factor to reflect the difference in functional equivalence where the output flow does not reach the functional equivalence of the substituting process.

In module D, substitution effects have been calculated only for the resulting net output flow.

The amount of secondary material output, which is for all practical purposes able to replace one to one the input of secondary material as a closed-loop, is allocated to the product system under study and not to module D. For details on secondary materials entering the system boundaries, please refer to section 1.14.1 General assumptions.

1.19CRITICAL REVIEW

The background LCA model and the report was critical reviewed by both Fei Ngeow (LCD Coach) and Richard Haynes (co-founder and co-CEO), eTool PTY LTD.

Fei Ngeow is a competent LCA practitioner and a Specialist user of eToolLCD. She has been working at eTool since 2013 and has completed over 40 LCAs including:

- LCA of a 2-story residential triplex building at White Gum Valley, Perth. Conducted for LandCorp. The primary motivation was to generate an as-designed footprint report. Completed June 2019.
- LCA of a 2-story residential dwelling at White Gum Valley, Perth. Conducted for LandCorp. The primary motivation was to generate an as-designed footprint report. Completed June 2019.
- LCA of the Amer Sport Warehouse Centre at Braeside, Victoria. Conducted for Sustainable Development Consultants Pty Ltd. The primary motivation was for Green Star Certification. Completed in May 2019.

A critical review was be carried out according to ISO 14040: 2006, clause 7.3.2, ISO 14044: 2006 and ISO 14071 (2014). The study was also be reviewed against the requirements of EN 15978.

2 LIFE CYCLE INVENTORY

The life cycle inventory section details the inputs and outputs for the materials, energy, and water use associated with the life cycle of the building. For inventory details on items not listed in this section, but have been included in the life cycle model, please refer to section 7 - APPENDIX B - DETAILED LCI TABLES.

2.1 BASE CASE DESIGN

The floor plans and material take-off schedules for the Cottage Lot Passive Solar House base case design were used to derive inventory records that were entered into the eToolLCD LCA software. The inventory records and life cycle datasets selected to model the Cottage Lot Base Case Design are listed below in Table 7.

Table 7 Life cycle inventory records and datasets for the Cottage Lot Base Case Design

Item	Quantity	Units	Notes	Dataset/Template	Updated
Concrete slab	167	m^2	100mm Concrete Slab - 167m^2, , Steel Reinforcing 200x200 , Mesh 8mm Wire	Concrete Floor - 100mm slab on ground (including 30MPa concrete, concrete pump, SL82 reo mesh, membrane, sand bed, compaction)	
Perimeter Footing Beam	9	m^3	500mm High x 300mm Wide, Perimeter Footing Beam - 60 lm	Concrete Pad Footings - 4% reo by volume, 40MPa (m^3)	
Timber deck	28	m^2	Timber Deck 28m^2	External timber deck (Alfresco)	
Concrete Pad	94	m^2	100mm Concrete Pad 94m^2, Steel Reinforcing 200x200 Mesh 6mm Wire	Concrete Floor - 100mm slab on ground (including 30MPa concrete, concrete pump, SL62 reo mesh, membrane, sand bed, compaction)	
Sand Pad	6.6	m^3	100mm Sand Pad 66m^2	Sand infill & compaction	
Carpet	48.7	m^2		Floor Covering - Carpet (glue down/Nylon)	
Tile	16	m^2		Floor Covering - Tiles (ceramic/2mm)	
Tile – Living areas	79	m^2		Floor Finish - Grind+PU Coated Polished Concrete (PU coating adjusted, no ppl)	
Ceilings	157.4	m^2	House floor covering area 141 m^2 - Living room 30m^2 horiz, 111 m^2 + 34.6 m^2((3.1+0.86+3.1)x4.9) living room raked ceiling, plus store ceiling 11.8 m^2, total 145.6 m^2 (excl store), 157.4 m^2 (incl store)	Ceiling - Plasterboard+paint	

Item	Quantity	Units	Notes	Dataset/Template	Updated
Rainwater Tank	134	kL of Rainwater used	Zincalume Rainwater Tanks (2x) 5m diam. x 2.2m high 44,000 L ea., pump and fittings	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	
Rainwater treatment	1	ea	Residential UV Water Treatment System (45W continuous consumption)	Residential UV Water Treatment System (45W)	
Timber posts	15.6	lm	120mm x 120mm x 2.6m, Timber posts (x10), minus 4 posts that are included in the carport	Timber post, hardwood, 120mm x 120mm, finished	
Exterior walls (net)	120.08	m^2	Gross Exterior Walls - 54.4 lm x 2.6m = 141.4m^2 + 6m^2 gable - less windows and doors of 27.32m^2, Total: 120.08m^2 of Net Exterior Wall	Masonry Wall - Double Brick (90/50/90) paint, concrete render ext, plaster render int (no insulation, no foundation, no plasterboard) [WEV]	
Interior walls (net)	116.33	m^2	Gross Interior Walls - 48.25 lm x 2.6 = 125.45m^2 + 6m^2 gable - less 9 interior doors totalling 15.12m^2, Total: 116.33m^2 of Net Interior Wall	Masonry Wall - Single Brick (110) internal (paint, plaster render int, no insulation, no foundation, no plasterboard) [WEV]	
Store walls (net)	32.34	m^2	Gross Store Walls - 15.7 lm x 2.4m = 37.7m^2 - less doors and openings of 5.36m^2, Total: 32.34m^2 of Net Store Wall	Masonry Wall - Single Brick (110) concrete render ext, (no insulation, no foundation) [WEV]	
Timber Shade Structures	4	m^2	2 x 2m^2 timber shade structures	Timber Solar Shade Awning (no covering)	
Solar Pergola	27	m^2	Timber + Clear, Corrigated Perspex	Timber Solar Shade Awning or Pergola	
Roofing, house and porch (m^2 horiz)	191	m^2	Corrigated Zincalume Roofing including Timber Framing / Trusses, Roof Area 191m^2. (115.5%, Angle Adjust, Total Roof Area: 220.6m^2)	Roof - TimberTruss/SteelSheeting/25°Pitch, no insulation (WEV)	
Roof insulation	191	m^2	Updated from R4.0 Fibreglass to R6.0 Rockwool batts	Bulk Insulation - Rockwool (R6.0)	v2
Roofing, carport and store (m^2 horiz)	61	m^2	Corrigated Zincalume, Timber Framing / Trusses, Roof Area 61m^2. (100.37% Angle Adjust, Total Roof Area: 61.23m^2)	Carport roof - timber frame, steel covering, no foundation, insulation or ceiling (WEV)	
Double hung windows	7.8	m^2	See windows and doors table for details	Windows, Residential Aluminium Single Glaze, fly screen	
Sliding windows	4.26	m^2	See windows and doors table for details	Windows, Residential Aluminium Single Glaze, fly screen	
Exterior doors	6.516	m^2	See windows and doors table for details	External Door - SolidCoreTimber/WoodenJam/Painted (m^2)	

Item	Quantity	Units	Notes	Dataset/Template	Updated
Awning windows	0.5	m^2	See windows and doors table for details	Windows, Residential Aluminium Single Glaze, fly screen	
Sliding doors	4.2	m^2	See windows and doors table for details	External Glass Sliding Door - commercial+hardware	
Internal doors	18.48	ea	18.48 m^2, 11 doors @1.68m^2/ea, See windows and doors table for details	Internal Door - HollowCoreTimber/WoodenJam/painted (m^2)	
Solar PV	6.6	kWp	Assumed tilt 34 degrees (optimum, on tilt frames), azimuth 0 degrees, 6.6 kWp solar PV modules, 5 kW inverter, produces 9,935 kWh/year. Updated from 5.5 to 6.6 kWp.	Solar PV System - Witchcliffe (SAM 1kWp, tilt 34d, azi 0d)	v2
Lighting	1	Fully Fitted Building		Lighting Residential LED Med Natural Light	
Refrigerator	1	refrigerator		Refrigeration, Residential Detailed (AUS) Op&Em	
Appliances, high-efficiency (ongoing)	1	Average Household Appliance Energy Demand	Updated from Appliances, average efficiency to high-efficiency (ongoing)	Appliances, High-efficiency (AUS) - Op&Em (ongoing high-efficiency)	v2
Hot water system	1	315L Electric heat pump hot water system(s)	Updated from electric boost solar hot water system	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	v2
Wastewater treatment	134	kL		Water treatment (1 kL/year, WEV)	
Heating and cooling	79	m^2 of floor area	AC unit changed to service living area only (kitchen, dining, lounge)	HVAC - Generic Operational HVAC (incl embodied) (WEV)	v2
Plumbing, Water and Sewerage Connection, Residential	1	residence		Plumbing, Water and Sewerage Connection, Residential	

The study involved the customisation of existing eToolLCD building material templates and the production of new templates. Where changes have been made to existing templates or new templates have been created for the base case design, they are included in Table 8 below.

Table 8 Assumptions to the customised datasets/templates used in the Cottage Lot Base Case Design

Dataset/Template	Parent Dataset/Template	Assumptions
Concrete Floor - 100mm slab on ground (including 30MPa concrete pump SL82 reo mesh membrane sand bed compaction)	Concrete Floor - 100mm slab on ground, 25MPa, 3.8% reo	- Reo mesh changed from 3.8% to SL82 - concrete grade changed to 30MPa

Dataset/Template	Parent Dataset/Template	Assumptions
Concrete Floor - 100mm slab on ground (including 30MPa concrete pump SL62 reo mesh membrane sand bed compaction)	Concrete Floor - 100mm slab on ground, 25MPa, 3.8% reo	- Reo mesh changed from 3.8% to SL62 - concrete grade changed to 30MPa
88kL Rainwater tanks and Pump for Residence (2x44kL steel) (WEV)	10,000L Rainwater tank and Pump for Residence (Above Ground)	- tank material changed from HDPE to Steel | Coated Sheet | Galvanised (zinc coated) | Industry Average. Note that Zinc coated steel rather than ZincAlum steel is typically used in rainwater tanks (Bluescope 2006) - tank size changed from 1x10kL to 2x44kL, mass per tank from 10kL - mass of steel for tank calculated based on 5m dia, 2.25m height, 1mm thick zinc coated steel (Zincform for Aquaplate), (Heritage Water Tanks 2019a) - HDPE liner mass calculated based on 0.7mm thickness (Heritage Water Tanks 2019b) and the calculated internal surface area of tank
Residential UV Water Treatment System (45W)	-	New template based on Davey Microlene Aquashield Centurion UV system (Davey 2017). * 45W continuous electricity consumption * 0.4 kg polypropylene Water cartridges (Stefani 2019), replaced annually (Davey 2017) * 1# Fluro bulb replaced annually (Davey 2017) * 1.8 kg polypropylene Filter housing (Davey 2017) * 2.0 kg stainless steel housing for UV bulb (estimate) * 1 kg aluminium bracket (estimated)
Masonry Wall - Double Brick (110/50/110) paint, concrete render ext, plaster render int (no insulation, no foundation, no plasterboard) [WEV]	- Masonry Wall - Double Brick (90/50/90)+ins+fd+paint+concrete render+PB - Masonry Wall - Single Brick (110mm) - Internal Finish - Plaster Render (13mm)	- Brick/Masonry Wall template (Masonry Wall - Single Brick (90mm)) changed to Masonry Wall - Single Brick (110mm) - insulation removed (not included in base design) - foundation removed (included separately) - plasterboard removed and Internal Finish - Plaster Render (13mm) (Validated) added
Masonry Wall - Single Brick (110) internal (paint plaster render int no insulation no foundation no plasterboard) [WEV]	- Masonry Wall - Double Brick (90/50/90)+ins+fd+paint+concrete render+PB - Masonry Wall - Single Brick (110mm) - Internal Finish - Plaster Render (13mm)	- Brick/Masonry Wall template (Masonry Wall - Single Brick (90mm)) changed to Masonry Wall - Single Brick (110mm) - quantity of Masonry Wall changed from 2m2 to 1m2 - insulation removed (not included in base design) - foundation removed (on slab) - plasterboard removed and

Dataset/Template	Parent Dataset/Template	Assumptions
		Internal Finish - Plaster Render (13mm) (Validated) added both sides of wall - Finish quantities added to both sides of wall
Masonry Wall - Single Brick (110) concrete render ext (no insulation no foundation) [WEV]	- Masonry Wall - Single Brick (110mm) - External Finish - 13mm Render (Cement)	Based on Validated templates.
Timber Solar Shade Awning (no covering)	Timber Solar Shade Awning or Pergola	Posts and polycarbonate sheeting removed as they are not applicable in the design
Carport roof - timber frame steel covering no foundation insulation or ceiling (WEV)	- Pergola (timber) - covered - Roof - TimberTruss/SteelSheeting/5°Pitch/Raking Ceiling	- Based on Pergola (timber) - covered template - nested Roof templates swapped from 10° Pitch to 5° Pitch - insulation and plaster ceilings removed
External Glass Sliding Door (m2 incl. hardware)	External Glass Sliding Door - commercial+hardware	- adjusted to 1m^2 basis. - nested template - Windows single glazed aluminium frame individual components (Public)
Solar PV System - Witchcliffe (SAM 1kWp, tilt 34d, azi 0d)	Solar PV System - Zone 3 (Perth)	- Supply, installation, maintenance and generation of 1kW Monocrystalyne Solar System. - 6.6 kWp system produces 9,934 kWh/year, 1505 kWh/kWp/year or 5,419 MJ/kWp/year. - Generation based on NREL SAM modelling for Witchcliffe, Tilt 34 degrees, azimuth 0 degrees. - solar data for 2007-2016 (European Commission 2017).
HWS - Heat Pump Hot Water System (315L, CO2, high COP)	HWS - Heat Pump (240L)	Inventory updated to be based on: Moore, A. D., Urmee, T., Bahri, P. A., Rezvani, S., & Baverstock, G. F. (2017). Life cycle assessment of domestic hot water systems in Australia. Renewable Energy, 103, 187–196. https://doi.org/10.1016/j.renene.2016.09.062 - CO2 refrigerant - COP of 5.6 (Sanden 2019) - 316 Stainless tank, 70 kg - 48 kg 5kW heat pump, LCI based on HVAC Air Source Heat Pump Embodied template - calculated electricity consumption of 2.1 kWh/d, 2759.4 MJ/year (calculated following AS/NZS 4234:(2011) which assumes annual cold water temperature of 17.7°C, electricity consumption of 11.6 kWh/d for a 315L electric storage hot water system to

Dataset/Template	Parent Dataset/Template	Assumptions
		produce 200L of hot water per day at 60°C. Estimated daily electricity consumption is calculated by dividing the daily electricity consumption of a standard 315L electric storage hot water system by the COP).
Water treatment (1 kL/year WEV)		New template that treats 1kL of waste water using - - Water Removal and Treatment , Water treatment: General
HVAC - Generic Operational HVAC (incl embodied) (WEV)	HVAC Air Source Heat Pump Embodied (multi-split) HVAC Air Source Heat Pump - COP/EER 3 (operational)	Used to condition the living space only (lounge, kitchen, dining).
Timber post, hardwood, 120mm x 120mm, finished		New template created using - - Timber | General | Industry Average, Frame, Hardwood posts 120mm x 120mm, 1m - Wood Stain External Finish
Roof - TimberTruss/SteelSheeting/25° Pitch, no insulation (WEV)	Roof - TimberTruss/SteelSheeting/25° Pitch	- insulation removed as it is included separately in the model to enable scenario analysis using different insulation types
HVAC Residential Ceiling Fans		Fans used in the bedrooms.

2.1.1 Operational energy

The operational energy for the Base Case Design is tabled below in Table 9.

Table 9 Operational energy for the Base Case Design (high-efficiency appliances)

Category	Description	Units	Annual Quantity
HVAC	Heating	kWh/year	1,318
Domestic Water Heating	Heat Pump Energy Demand	kWh/year	767
Refrigeration	Primary Refrigerator / Freezer Unit	kWh/year	589
Appliances | Entertainment	Computers, other entertainment and standby	kWh/year	420
Water Supply	UV sterilisation unit	kWh/year	394
Lighting	Lighting Electricity Consumption	kWh/year	298
Water Supply	Pressure pump	kWh/year	268
Refrigeration	Freezers	kWh/year	268
Refrigeration	Allowance for secondary refrigeration units	kWh/year	214
Workshops, Garage & Misc	Miscellaneous electricity demand	kWh/year	189
Miscellaneous	Dishwashing machines (MEPS 4 Star)	kWh/year	183

Category	Description	Units	Annual Quantity
Appliances | Laundry Appliances	Clothes washing machine (MEPS 5 Star)	kWh/year	88
Appliances | Entertainment	Televisions (MEPS 7 Star)	kWh/year	82
Appliances | Laundry Appliances	Clothes Dryers (MEPS 6 Star)	kWh/year	79
HVAC	Cooling	kWh/year	27
HVAC	Ceiling fans	kWh/year	6
Total		**kWh/year**	**5,190**
Total		**kWh/day**	**14.2**
Power Generation and Storage	Solar Generation	kWh/year	-9,935
Net		kWh/year	-4,745

The average electricity consumption of the Base Case Design is 14.2 kWh/day which is the same as the average household in Western Australia (WA) (AMEC 2018), however, the WA average household figure includes reductions achieved through the use of solar PV and the Base Case Design figure excludes solar PV. The Base Case Design also includes electricity consumption for water pressure pump and UV treatment which is 13% of the annual electricity consumption.

The operational energy of the other building design options modelled has been considered to be the same as the base case design except for:

- The electricity consumption of the HVAC unit for heating and cooling, which are calculated by the eToolLCD LCA software (Richard Haynes 2019), are based on heating and cooling loads from the BERS Pro thermal modelling software.
- The electricity consumption of the rainwater pressure pump for the reduction in water use scenarios
- The scenario on the use of average appliances rather than high-efficiency appliances

2.1.1.1 Thermal performance

The thermal assessment results for the different building design options were modelled by ESD Australia using the NatHERS accredited software BERS Pro. The thermal assessment results subsequently are used in the life cycle assessment modelling to calculate the energy consumption of the heating and cooling systems of the building.

It is important to consider the key assumptions in the NatHERS thermal assessment modelling when interpreting the results. These key assumptions in the underlying NatHERS modelling and Chenath engine include (Chen 2016):

Occupancy

- For living spaces: thermal comfort is maintained from 7.00am to midnight
- For sleeping spaces: thermal comfort is maintained from 4.00pm to 9.00am

Thermostat Set Points

- For sleeping spaces (including bedrooms and other spaces closely associated with bedrooms): a minimum heating thermostat setting of 18 degrees Celsius is used from 7.00am to 9.00am and from 4.00pm to midnight; and a heating setting of 15 degrees Celsius from midnight to 7.00am.
- For living spaces (including kitchens and other spaces typically used during waking hours): a minimum heating thermostat setting of 20 degrees Celsius is applied.
- The cooling methodology is based on the Effective Temperature method of calculating thermal comfort. The cooling thermostat setting varies according to the climate zone to account for the acclimatisation of local residents.

Infiltration

- Infiltration does take into account a range of factors including wind speed, openings, vents, cavities, types of windows/doors etc but it doesn't allow for very well sealed homes (e.g. Passive Haus standard).

2.1.1.2 Photovoltaic solar system

The energy production of the photovoltaic solar system is modelled using the NREL System Advisor Model (SAM) software (National Renewable Energy Laboratory 2016) and site-specific design parameters including the solar equipment specifications, installation parameters (azimuth, inclination), the solar resource of the site, and system-specific losses. Details are documented below.

- The initial system size modelled was 5.5 kWp (solar array) that was increased in version 2 to 6.6 kWp based on the requirements of the draft Design Guidelines.
- Due to the relative size of the photovoltaic solar system and the use of shared community batteries, it has been conservatively assumed that 95% of the consumption is from onsite generation and 5% is imported from the grid.

Electricity not consumed onsite, or used to charge the community battery, has been assumed to be exported to the grid.

- The modelling assumptions used are:
  - Average solar resource data for Witchlcliffe, Australia from 2006 to 2017 (European Commission 2017)
  - Solar panel mounting fixed; solar panel tilt 34 degrees; solar azimuth 0 degrees (north facing)
  - Inverter capacity 5 kWp
  - No shading losses

The annual energy production of the photovoltaic solar system is presented below in Table 10.

Table 10 Annual energy production of the photovoltaic solar system

Item	Quantity	Units	Reference	Comments
6.6 kWp Annual energy production	9,934	kWh/year	Modelled using the NREL System Advisor Model (SAM) software	(National Renewable Energy Laboratory 2016)

The production, transport, installation, operation, maintenance, replacement and disposal of the solar system components have also been included in the building LCA model. Refer to the separate detailed inventory document for further details.

2.1.1.3 Electricity supply mix

The WA electricity supply mix that is offset by the production of electricity from the solar system is based on the most recent AusLCI data (ALCAS 2016). For this period electricity was supplied from: black coal (48.8%), natural gas (43.2%), wind (3.7%), solar photovoltaic (3.2%), landfill gas (0.7%), oil (0.2%), and other (0.2%). Refer to Table 11 below for details. The global warming potential emission factor of the electricity supply mix (electricity, low voltage, Western Australia, including distribution losses) is 0.849 kg CO_2e/kWh.

It is expected that the share of electricity generation from renewable sources in the WA grid will increase; however, the life cycle modelling of the study period is based on the existing grid mix and emission factors in the AusLCI data (ALCAS 2016).

Table 11 WA electricity supply mix (ALCAS 2016)

Item	Quantity	Units	Reference
Black coal	48.8	%	(ALCAS 2016)
Natural gas	43.2	%	(ALCAS 2016)
Wind	3.7	%	(ALCAS 2016)
Solar photovoltaic	3.2	%	(ALCAS 2016)
Landfill gas	0.7	%	(ALCAS 2016)
Oil	0.2	%	(ALCAS 2016)
Other	0.2	%	(ALCAS 2016)
Total	100	%	

2.2 DESIGN OPTIONS

The following section documents the inventory and assumptions for the Design Options investigated.

2.2.1 Walls

The walls in the Base Case Design were assumed to be double brick external walls (with no cavity insulation) and single brick internal walls (painted, plaster render). The wall design options are summarised below in Table 12. Further details for each of the wall types are provided in the individual sections that follow.

For consistency, the internal wall types for all of the Design Options were assumed to be timber frames with painted plasterboard except where otherwise stated.

A standard assumption for all wall Design Options was that the wall for the store/workshop and drying area was single brick masonry wall with external concrete render.

Table 12 Summary of Design Options - Walls

Design Option	Details	External Wall	Internal Wall
Base Case Design	External walls - Masonry Wall - Double Brick (90/50/90mm) paint, concrete render ext, plaster render internal finishing. Internal walls - Masonry Wall - Single Brick (110mm) internal (paint, plaster render internal finishing.	Masonry Wall - Double Brick (90/50/90) paint, concrete render ext, plaster render int (no insulation, no foundation, no plasterboard) (WEV)	Masonry Wall - Single Brick (110) internal (paint, plaster render int, no insulation, no foundation, no plasterboard) (WEV)
Hempcrete	330mm hempcrete* (imported from Europe) with timber structure and internal/external lime plaster[11], R4.1 (modelled) achieved using Tradical Thermo lime biner (Lhoist 2018) in hempcrete and internal wall lining internal wall with Thermo lime binder. A 300mm hempcrete wall plus 10mm internal lining using non-thermo lime binder (PF70) is R3.0 (Lhoist 2018).	330mm Hempcrete external insulating wall, Thermo binders, embedded framing, external and internal finishes (WEV)	Timber Frame (90mm studs at 600, internal) - R1.5 + PB lining 2 sides
Timber frame	Timber Frame - 90mm timber frame, vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape), R3.0 recycled poly batt insulation (80% recycled), 25x45mm timber battens, hardwood cladding, plasterboard	90mm Timber Stud External Wall with battens - R3 poly ins, pb paint finish int, Timber clad stained Ext (WEV)	Timber Frame (90mm studs at 600, internal) - R1.5 + PB lining 2 sides
Steel frame	Steel Frame - 90mm steel frame (steel C channel type: tracks for top plate & bottom plate, studs and noggins), vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape), R3.0 recycled poly batt insulation (80% recycled), hardwood cladding, plasterboard	Steel stud (600mm centre)- hardwood weatherboard clad+pb+poly insul+finish (WEV)	Timber Frame (90mm studs at 600, internal) - R1.5 + PB lining 2 sides

[11] The original scope was for internal sealant only (no plaster inside), however, the standard OZHemp/Tradical method is to use an internal lime coating. The quantity of lime used for the internal coating is minimal compared to the lime used in the external coating and the hempcrete wall so it has minor effect on the results.

Design Option	Details	External Wall	Internal Wall
Straw bale infill	Straw Bale (infill) - 450mm straw bale with timber structure and lime render internal and external. Framing - 120 x 120mm poles (2400mm centres), assume same construction as per load bearing straw bale walls.	External wall - 450mm straw bale infill wall with timber structure and 50mm lime plaster internal and external (WEV)	Timber Frame (90mm studs at 600, internal) - R1.5 + PB lining 2 sides
SIPS	175mm SIPS,11mm OSB, 150mm EPS, R4.4 - R4.65 (SIPS Industries Australia 2017). Templates customised to increase EPS core and timber to 153mm. Includes SIPs, associated timber framing, plasterboard interior with paint, hardwood external cladding with stain, timber counter battens, membrane.	External wall - 175mm Structural Insulated Panel (SIP), EPS core (Superstructure) (v2 WEV)	Timber Frame (90mm studs at 600, internal) - R1.5 + PB lining 2 sides
Timber frame reverse brick veneer (lightweight brick)	Timber frame reverse brick veneer (lightweight brick) - 90mm timber frame, vapour permeable membrane wall wrap (installed with overlaps, window frames, top plate and bottom plate all sealed with tape), R3 fibreglass batt insulation, 25x45mm timber battens, hardwood cladding, single leaf internal lightweight/fast brick (305 x 90 x 162mm, 5.15kg ea), wet plaster	90mm Timber Stud External Wall with lightweight brick veneer (single leaf internal) battens - R3 poly ins, pb paint finish int, Timber clad stained Ext (WEV)	Timber Frame (90mm studs at 600, internal) - R1.5 + PB lining 2 sides

2.2.1.1 Hempcrete

The details of the modelling for this wall type are summarised below (see Table 13).

Table 13 Life cycle inventory for Hempcrete walls

Template	Parent template	Changes to parent template
330mm Hempcrete external insulating wall, Thermo binders, embedded framing, external and internal finishes (WEV)	-	- Hempcrete 300mm (hemp shiv-lime composite and timber frame, Thermo lime binder, no finishes) - Wall Finish - Internal Hemp-lime coating (10mm, Thermo lime binder) - Wall Finish - External coating for Hempcrete wall (20mm)

Template	Parent template	Changes to parent template
Hempcrete 300mm (hemp shiv-lime composite and timber frame, Thermo lime binder, no finishes)	Framing - 100mm Timber Stud (600mm centres)	Parent template modified to include: - Framing - 100mm Timber Stud (600mm centres) - Hemp shiv (EU) - Plant Based Products (non Timber) | Straw Bales | Unspecified | Industry Average, Wall finishes, Hemp shiv (straw proxy), Based on Inventory data using straw bales as proxy, assuming grown and transported from EU, container ship. - Lime Binder (EU) - Cements and Limes | Lime | Industry Average, Wall finishes, Binder, lime, assuming transported from EU, container ship
Wall Finish - Internal Hemp-lime coating (10mm, Thermo lime binder)	-	- Hemp shiv (EU) - Plant Based Products (non Timber) | Straw Bales | Unspecified | Industry Average, Wall finishes, Hemp shiv (straw proxy), Based on Inventory data using straw bales as proxy, assuming grown and transported from EU, container ship. - Lime Binder (EU) - Cements and Limes | Lime | Industry Average, Wall finishes, Binder, lime, assuming transported from EU, container ship
Wall Finish - External coating for Hempcrete wall (20mm)	-	New template created, includes Base Coat, Brown Coat, and Exterior Finish. Details from Lhoist. (2018). Tradical® Hempcretes. LCI uses - - Bulk Aggregates Sands and Soils | Aggregate (Compacted) | Unspecified | Industry Average - Cements and Limes | Lime | Industry Average

For the Hempcrete wall option, the LCA model uses straw as a proxy for the Hemp Shiv which, in the absence of detailed life cycle inventory data, is considered to be a reasonable assumption. Straw bales have a negative carbon footprint due to the storage of biogenic carbon in the straw[12]. The impacts for the additional processing of the hemp shiv – compared to straw bale – would increase the environmental impacts but they should be marginal compared to the impacts associated with the other materials used in the Hempcrete wall system.

On a per mass basis (excluding water and the internal/external render finishes), a Hempcrete wall is composed of 54% lime, 31% hemp shiv, and 15% timber (frame enclosed in hempcrete) – see Table 14.

[12] The assumptions are that the straw bales are produced as a coproduct from wheat. The environmental burdens are economically allocated (which is typical for these types of co-products). The wheat grain is allocated 90% of the environmental burden (based on the long-term average market price of wheat grain) and the straw bale is allocated 10% (based on the long-term average price of straw bales). The transport of the straw is also included.
Additional benefits from avoiding burning the straw in-situ are not included to avoid double-counting.

Lime binder is produced from limestone that is fired in a kiln to remove the additional carbon and oxygen which are released as carbon dioxide (similar to cement production). The type of lime included in the eToolLCD database was listed as “Cements and Limes | Lime | Unspecified”. Further investigation with the database provider revealed that the type of lime include in the database was quicklime (hydraulic lime, calcium oxide) rather than hydrated lime (slacked lime, Calcium hydroxide) that is used for hempcrete (and strawbale lime render) (Lhoist 2016). An adjustment was made to the quantities of lime to account for the difference (-20%) between quicklime (calcium oxide) and hydrated lime (calcium hydroxide) (Tim Grant 2020). Adjustments were also made to the transport distances (+20%) to account for the quantities of lime adjustment and to ensure that the results for transport of lime were representative.

The eToolLCD database did not include building templates for Hempcrete walls. The detailed inventory data used to create new templates were calculated from Lhoist (2018) specifications. The specifications were cross-checked against other reference sources (Piot et al. 2017; Pretot, Collet, and Garnier 2014).

Table 14 Detailed inventory data for Hempcrete wall and renders (Lhoist 2018)

Item	Item	Details	Quantity	Units
Hempcrete wall (excl. render), 300mm thickness		Hemp shiv, Chanvribat, 20 kg/bag, 200L net volume	30.1	kg/m2
		Binder, Tradical Thermo®	51.8	kg/m2
		Timber frame (studs, nogs, top/bottom plates	14.7	kg/m2
External coating (20mm)	Base coat, 5mm	Binder, Tradical® PF 80 M, 30 kg/bag, at 850kg/m3	3.8	kg/m2
		Sand, 30 kg, 0/4 40L@750kg/m3	3.8	kg/m2
	Brown coat, 10mm	Binder, Tradical® PF 70, 22 kg/bag @650kg/m3	3.7	kg/m2
		Sand, 45kg 60L 0/4 sand @750kg/m3	7.5	kg/m2
	Exterior finish, 5mm	Binder, Tradical® PF 80 M, 30 kg/bag, at 850kg/m3	2.5	kg/m2
		Sand, 45 kg, 0/4 40L@750kg/m3	3.8	kg/m2
Internal hemp-lime coating (10mm)		Hemp shiv, Chanvribat, 20 kg/bag, 200L render	1.3	kg/m2
		Binder, Tradical® PF 70, 22 kg/bag	3.3	kg/m2

The transport assumptions for the hemp shiv and lime base scenario (imported from Europe) and the locally produced scenario are presented below in Table 15.

Table 15 Transport distance assumptions for European and local hemp and lime production

Item	Rigid truck (km)	Articulated truck (km)	Container ship (km)
Hemp shiv (EU)	125	300	20,000
Hemp shiv (Local)	125	300	0
Lime (EU)	125	300	20,000
Lime (Local)	125	300	0

2.2.1.2 Timber frame

The details of the modelling for this wall type are summarised below in Table 16.

Table 16 Life cycle inventory for Timber Frame walls

Template	Parent template	Changes to parent template
90mm Timber Stud External Wall with battens - R3 poly ins, pb paint finish int, Timber clad stained Ext (WEV)	Timber Stud External Wall - Plywood finish int Hardwood Ext	Parent template modified to include: - Framing - 90x45mm Timber Stud (600mm centres) - Timber counter battens 25x45mm (New Zealand and Department of Building and Housing 2006) - Wood Stain External Finish - Wall Cladding - Weatherboard (19mm/timber), Hardwood data changed to Timber | General | Industry Average - Wall Lining - Plasterboard (12mm) - Internal Finish - Paint (standard) - Bulk insulation - 80% Recycled Polyester (R3.0) (WEV) - based on Inventory data

2.2.1.3 Steel frame

The details of the modelling for this wall type are summarised below in Table 17.

Table 17 Life cycle inventory for Steel Frame walls

Template	Parent template	Changes to parent template
Steel stud (600mm centre)-Timber weatherboard clad pb poly insul finish (WEV)	Steel stud (600mm centre)-steel clad+pb+insul+finish	Parent template modified to include: - Framing - 90mm Steel Stud (600mm Centres) - Internal Finish - Paint (standard) - Wall Lining - Plasterboard (12mm) - Bulk insulation - 80% Recycled Polyester (R3.0) - Wall Cladding - Weatherboard (19mm/hardwood) - External Finish - Paint (SuperStructure)

2.2.1.4 Straw bale (infill)

The details of the modelling for the Straw bale (infill) wall type are summarised below. The type of straw bale wall modelled uses straw to infill the timber post and beam structure.

The type of lime included in the eToolLCD database was listed as “Cements and Limes | Lime | Unspecified”. Further investigation with the database provider revealed that the type of lime include in the database was quicklime (hydraulic lime, calcium oxide) rather than hydrated lime (slacked lime, Calcium hydroxide) that is used strawbale lime render (Lhoist 2016). An adjustment was made to the quantities of lime to account for the difference (-20%) between quicklime (calcium oxide) and hydrated lime (calcium hydroxide) (Tim Grant 2020). Adjustments were also made to the transport distances (+20%) to account for the quantities of lime adjustment and to ensure that the results for transport of lime were representative.

Table 18 Life cycle inventory for Straw Bale walls

Template	Parent template	Changes to parent template
External wall - 450mm straw bale infill wall with timber structure and 50mm lime plaster internal and external (WEV)	Straw Bale Wall, Load Bearing, Lime Rendered	Parent template modified to include: - Straw Bale Wall, Load Bearing, Lime Rendered - Timber post, hardwood, 120mm x 120mm (2400mm centres).

2.2.1.5 Structural insulated panels (SIPS)

The details of the modelling for this wall type are summarised below.

Note that due to the airtight nature of the SIPS wall system it may require the use of an Energy Recovery Ventilator (ERV). Based on discussions with SIPS Industries (pers. Comms with Damien Madden August 2019) and Armcor Air Solutions, an additional scenario has been included where it has been assumed that an XCHANGE ERV ceiling mount heat recovery unit (XCM80P1) has been installed in the SIPS building and is controlled using a carbon dioxide sensor (Armcor Air Solutions 2016).

The energy consumption of the unit is based on Armcor Air Solutions (2016) of 126 W for 80 L/s scaled to requirement for 3 people at 10 L/second/person, assuming the house is occupied by 3 people 60% of the time (14 hours/day), totalling 0.66 kWh/day. It is important to ensure that automated controls are used with ERV units or there is a risk that they could consume more electricity than a less air tight building that is air-conditioned using an efficient heat pump system.

Although the unit is ~70% efficient at heat recovery (compared to 0% efficiency for air exchange with no heat recovery) this is not included in the modelling.

The embodied impacts associated with the production of the ERV have been excluded in this scenario due to the relatively minor contribution to the environmental impacts compared to the operational energy.

Table 19 Life cycle inventory for SIPS walls

Template	Parent template	Changes to parent template
External wall - 175mm Structural Insulated Panel (SIP), EPS core (Superstructure) (v2 WEV)	Walls - 165mm Structural Insulated Panel (SIP), EPS core (Superstructure)	Parent template modified to include: - Walls - 153mm Timber Framing for SIPs (Superstructure) (WEV) (SIPS Industries Australia 2017) - Wall Lining - Plasterboard (12mm) - Internal Finish - Paint (standard) - Wall Cladding - Weatherboard (19mm/hardwood) - External Finish - Paint (SuperStructure) - Timber counter battens for SIPS 50x50mm - Waterproof membrane (0.5mm thick)

2.2.1.6 Timber frame reverse brick veneer (lightweight brick)

The details of the modelling for the Timber frame reverse brick veneer wall type are summarised below (Table 20).

Additional scenarios are included for mudbrick veneer walls.

Table 20 Life cycle inventory for Timber frame reverse brick veneer (lightweight brick) walls

Template	Parent template	Changes to parent template
90mm Timber Stud External Wall with lightweight brick veneer (single leaf internal) battens - R3 poly ins, pb paint finish int, Timber clad stained Ext (WEV)	Timber Stud External Wall - Plywood finish int Hardwood Ext	Parent template modified to include: - Framing - 90x45mm Timber Stud (600mm centres) - Timber counter battens 25x45mm (New Zealand and Department of Building and Housing 2006) - Wood Stain External Finish - Wall Cladding - Weatherboard (19mm/timber), Hardwood data changed to Timber | General | Industry Average - Wall Lining - Plasterboard (12mm) - Internal Finish - Paint (standard) - Bulk insulation - 80% Recycled Polyester (R3.0) (WEV) - based on Inventory data - Masonry Wall - Single Lightweight Brick (90mm), light weight bricks 305 x 90 x 162mm, 5.15 kg/ea, mortar volume and trade hours adjusted accordingly.

2.2.1.7 External Cladding

Two different types of external wall cladding were modelled (see Table 21). The external cladding design option for fibre cement is compared against the Timber frame wall with local hardwood cladding as the Base Case Design does not include external cladding.

Table 21 Life cycle inventory for External cladding

Template	Parent template	Changes to parent template
90mm Timber Stud External Wall with battens - R3 poly ins, pb paint finish int, Fibre cement clad, painted Ext (WEV)	90mm Timber Stud External Wall with battens - R3 poly ins, pb paint finish int, Timber clad stained Ext (WEV)	Wall cladding and finish changed from 19mm Timber cladding and stain to - Wall Cladding - 9mm Compressed Fibre cement board (External) - Wall Finish - Paint (2 coat)

2.2.1.8 Windows

The background LCI database includes all of the window frame and glazing combinations as listed below, except for the low-e glass options which have been modelled based on the parent templates that have been modified to include thicker glass. Details for the frame and glazing combinations are presented below in Table 22.

For details on the thermal performance of the window options please refer back to section 1.8.2.3.

Table 22 Life cycle inventory for Window frames and glazing combinations

Window frame	Window glazing	Template	Changes to parent template
Aluminium (no thermal break)	Single glazing	Windows, Residential Aluminium Single Glaze, fly screen	
Aluminium (no thermal break)	6mm Single Glazed Low-E	Windows, Residential Aluminium Single Glaze 6mm low-e, fly screen	Parent template modifications: - material added for additional glass - Glass | Flat Glass | Industry Average, 3mm
Aluminium (no thermal break)	Double glazed	Windows, Residential Aluminium Double Glaze, fly screen	
Timber	Single glazing	Windows, Residential Timber frame, Single Glaze, fly screen	
Timber	6mm Single Glazed Low-E	Windows, Residential Timber Single Glaze 6mm low-e, fly screen	Parent template modifications: - material added for additional glass - Glass | Flat Glass | Industry Average, 3mm
Timber	Double glazed	Windows, Residential Timber frame, Double Glaze, fly screen	
uPVC	Single glazing	Windows, Residential PVC Single Glaze, Fly-screens	
uPVC	6mm Single Glazed Low-E	Windows, Residential PVC Single Glaze 6mm low-e, fly screen	Parent template modifications: - material added for additional glass - Glass | Flat Glass | Industry Average, 3mm
uPVC	Double glazed	Windows, Residential PVC Double Glaze, Fly-screens	
Aluminium (thermal break)	Single glazing	Not modelled - Thermally Broken frames are double glazed.	

Window frame	Window glazing	Template	Changes to parent template
Aluminium (thermal break)	6mm Single Glazed Low-E	Not modelled - Thermally Broken frames are double glazed.	
Aluminium (thermal break)	Double glazed	Windows, Residential Aluminium Double Glaze Thermal Break, fly screen	

Note that Aluminium frames with a thermal break are typically double glazed – modelling options for single glazed and low-e glazing were not available in the thermal assessment modelling software so further details have not been included in the table above.

2.2.1.9 Ceiling insulation

Seven different types of ceiling insulation were modelled as detailed in Table 23.

Hemp batts

Hemp batt insulation has been modelled based on specifications from Hempflax (2018):

- 90% hemp fibre
- 10% virgin PET (branded bico) fibre
- R4.0 160mm thickness, 5.68 kg/m^2 at 35,5 (kg/m^3)
- 21.6m^2/pallet, 518.4m^2/40ft container (assuming 24 pallets per 40ft container)

In the absence of specific inventory data for hemp fibres, straw was used as a proxy (Plant Based Products: non-Timber | Straw Bales | Unspecified | Industry Average). Transport assumptions were the same as for hemp shiv for the hempcrete – refer to Table 13 for further details.

Recycled cotton

Data for the recycled cotton batts are based on specifications from BondedLogic (2019):

- 90% post-consumer denim, 2.68kg/m^2
- 10% HDPE binder fibre, 0.3kg/m^2

In the absence of specific inventory data for recycled cotton, recycled cellulose fibre was used as a proxy for recycled denim. Transport distances from the US to Witchcliffe were included (600km articulated truck, 16 000km container ship, from Google Maps and Sea Distances (2018)).

Table 23 Life cycle inventory for Insulation

Template	Parent template	Changes to parent template
Bulk Insulation - Rockwool (R6.0)	Bulk Insulation - 100mm Rockwool (R2.8)	Parent template modifications: - Template item changed to - Insulation | Blankets and Batts | Mineral Wool | Blanket | R 4.0 | Industry Average

Template	Parent template	Changes to parent template
		- life changed to 50 years (life of ceiling) - quantity increased by 150% to increase from R4.0 to R6.0
Insulation - 275mm Fibreglass Batts (R6.0)	Bulk Insulation - Ceilings 210mm/R5 (fibreglass)	Insulation thickness increased from 210mm to 275mm to achieve R6.0
Bulk Insulation - Hemp batts (R6.0), EU	Bulk Insulation - Hemp batts (R4.0), EU	Parent template modifications: - insulation quantities scaled up by 150%
Bulk Insulation - Wool (R6.0)	Bulk Insulation - Polyester/Wool blend (R1.5)	Parent template modifications: - Template item changed to - Insulation | Blankets and Batts | Wool | R 4.0 | Industry Average - quantity increased by 150% to increase from R4.0 to R6.0
Bulk Insulation - Recycled Cotton (denim, R6.0)	Bulk Insulation - 100mm Rockwool (R2.8)	Parent template modifications: - Insulation changed to : * Insulation | Loose Fill | Cellulose Fibre | Loose Fill | Industry Average, Insulation, Recycled denim insulation * Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average, Insulation, Binder fibre Recycled denim (denim/cotton is mainly composed of cellulose fibre) R4.0 insulation batts * 155mm thick to achieve R4.0, 2.98 kg/m2 (Bonded Logic 2019) * 90% post consumer denim (cellulose used as proxy - assumes that the industry average dataset for cellulose insulation contains high % recycled fibres), 2.68kg/m2 (Bonded Logic 2019) * 10% HDPE binder fibre, 0.3kg/m2 * assume made in the US (by Bonded Logic) (600km artic truck, 16 000km sea) (Bonded Logic 2019; Google Maps 2019) * quantity of insulation increased to go from R4.0 to R6.0
Bulk Insulation - Polyester (R6.0), virgin	Bulk Insulation - Polyester 100mm (R2.5)	Parent template modifications: - Template item changed to - Insulation | Blankets and Batts | Polyester Batts | R 4.0 | Industry Average - life changed to 50 years (life of ceiling) (Rawlinsons 2011) - quantity increased by 150% to increase from R4.0 to R6.0
Bulk Insulation - Rigid Polystyrene (R6.0)	Bulk Insulation - 100mm Rockwool (R2.8)	Parent template modifications: - Template item changed to - Insulation | Rigid Foams and Boards | Polystyrene | 0% Recycled EPS | Industry Average Bulk Insulation - Rigid Polystyrene (R4.0) - life changed to 50 years (life of ceiling) (Rawlinsons 2011) Thickness 112 mm calculated based on: * R-Value = Thickness (m) / Thermal conductivity (W/mK) * Thermal conductivity 0.028 W/mK (Knauf Insulation 2019) - quantity increased by 150% to increase from R4.0 to R6.0

2.2.1.10 Flooring – Living areas and bedrooms

Details for the flooring design options modelled are included below in Table 24.

An additional scenario was included for a rammed earth floor that is installed directly on the ground with no concrete slab (Rammed Earth Floor (rock/sand base, no slab, finished)). The following changes were made to the Base Case design to model this design option:

- Slab size reduced by 79 m^2 (the area of flooring)
- Additional footing beam added 16.34m (4,240+4,850+7,250mm) to provide a foundation to the slab edge and internal walls

Table 24 Life cycle inventory for Flooring

Template	Parent template	Changes to parent template
Floor Covering - Tiles (ceramic/2mm)		-
Floor Finish - Grind+PU Coated Polished Concrete (PU coating adjusted)		-
Marmoleum		-
Floor Covering - Cork Tiles (oiled)		-
Floor Covering - 19mm timber, Glue direct to slab (finished)	Floor Covering - 12mm timber, Glue Down (Substructure)	Parent template modifications: - Added Wood Stain Internal finish - Removed substructure - Changed wood data from Hardwood to Timber | General | Industry Average - increased timber thickness to 19mm
Rammed Earth Floor (finished)		Information from (Bradley 2014) * HDPE lining * 25mm flooring layer * 4 parts of brickies sand, to 3 parts renderers clay * 0.29L of linseed oil per m2 (total) applied in 5 coats Inventory Data - - Rammed earth floor - Bulk Aggregates Sands and Soils | Rammed Earth (Compacted) | In situ earth. No cement (Compacted) | Industry Average - HDPE lining - Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average, Floors - Floor finishes - Paints and Finishes | Water Based | 1 Coat | Industry Average, Water based floor sealant (5 coats, 40 yr life, maint 20% every 10 years)
Rammed Earth Floor (rock/sand base, no slab, finished)		New template created based on Bradley (2014) to include: * 100mm road base (aggregate) * 95mm sand (20+75mm) * HDPE lining * 25mm flooring layer * 4 parts of brickies sand, to 3 parts renderers clay * 0.29L of linseed oil per m2 (total) applied in 5 coats Inventory Data -

Template	Parent template	Changes to parent template
		- Rammed earth floor - Bulk Aggregates Sands and Soils | Rammed Earth (Compacted) | In situ earth. No cement (Compacted) | Industry Average - HDPE lining - Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average, Floors - Floor finishes - Paints and Finishes | Water Based | 1 Coat | Industry Average, Water based floor sealant (5 coats, 40 yr life, maint 20% every 10 years) - No concrete slab Note, the design includes adjustment to the slab perimeter beam/foundation to support internal walls.
Floor Covering - Carpet (glue down/Nylon)		-
Carpet, Tack Down Wool, Felt Underlay		-

2.2.1.11 Foundations

Two options were modelled for the foundations as documented in Table 25

Table 25 Life cycle inventory for Foundations

Template	Parent template	Changes to parent template
Concrete Floor - 100mm slab on ground (including 30MPa concrete, 30% Fly ash, concrete pump, SL62 reo mesh, membrane, sand bed, compaction)	Concrete Floor - 100mm slab on ground (including 30MPa concrete, concrete pump, SL62 reo mesh, membrane, sand bed, compaction)	Parent template modifications: - Concrete changed to 30% Fly ash
Concrete slab edge insulation (R1.5, XPS, 42 mm wide x 500 mm height)	Floor, slab edge insulation	- dimensions changed to depth of footing beam (500 mm), 42 mm Styroboard XPS R1.5 (Styroboard 2018) - fibre cement sheet removed

2.2.2 Additional scenarios

Several additional scenarios were investigated to determine their effect on the LCA results. Details of these scenarios are provided below.

2.2.2.1 Reduction in water use and increasing tank life

Two additional scenarios were modelled to measure the effect of reducing the water use of the dwelling and increasing the tank life.

Reducing the average water use per person from 122 L/person/day to 100 L/person/day was investigated. This reduction in average water use would:

- Reduce the size of rainwater tanks required

- Reduce the electricity consumption associated with pressure pump operation
- Reduce the amount of wastewater needs to be treated by the wastewater plant

There would be no reduction in the electricity consumption of the UV treatment system as it operates continuously regardless of the quantity of water treated.

The modelling assumptions for this scenario were to:

- Reduce the size of the rainwater tanks from 88 kL (2 x 44 kL) to one 60 kL tank.
- Reduce the total annual water consumption from 134 kL to 109.5 kL
- Reduce the total annual wastewater from 134 kL to 109.5 kL

The effect of rainwater tank life on the results was investigated by changing the life of the tank and liner from 20 years (typical warranty period) to 40 years. Western Australian tank manufacturers such as Heritage Rainwater Tanks have been manufacturing for 20 years and expect their tanks and liners to last greater than 30 years[13].

2.2.2.2 Use of average appliances

The Base Case Design assumes the use of high-efficiency appliances. An additional scenario has been investigated where average appliances have been used. The details for average appliances and high-efficiency appliances are presented below in Table 26.

Table 26 Details of average efficiency appliances and high-efficiency appliances

Item	Average efficiency		High-efficiency	
	Description	kWh/year	Description	kWh/year
Televisions	MEPS 2.2 Star	630	MEPS 7 Star	82
Clothes washing machine	MEPS 1 Star	421	MEPS 5 Star	88
Computers, other entertainment and standby		420		420
Dishwasher	MEPS 1 Star	282	MEPS 4 Star	183
Miscellaneous electricity demand		189		189
Clothes Dryer	MEPS 1 Star	180	MEPS 6 Star	79

The use of different efficiency refrigerators and freezers have not been modelled in this scenario, only the appliances listed above.

[13] Pers comms (telephone) Heritage Rainwater Tanks 4th September 2019.

Note that for the high-efficiency appliances, the eToolLCD template was adjusted so that the use of high-efficiency appliances continued, rather than dropping back to average efficiency appliances, after they were replaced.

3 RESULTS AND INTERPRETATION

The results and interpretation are presented in two sections:

4.1 Thermal assessment

4.2 Life cycle assessment

The thermal assessment results are from the thermal modelling conducted by ESD Australia using BERS Pro software. The thermal assessment results subsequently are used in the life cycle assessment modelling to calculate the energy consumption of the heating and cooling systems of the building.

3.1 THERMAL ASSESSMENT

The results of the thermal assessment are presented below (Table 28) for the Base Case Design and the Design Options.

Where the term 'default options' is used it refers to the type of internal wall used for each of the building types. The default option for the Base Case Design is double brick external walls (no cavity insulation) and single brick internal walls. The default options for the other wall types are timber frame (with painted plasterboard and internal insulation). Any variations from these default assumptions is documented.

Only the Design Options that have an influence on the thermal assessment results are presented. For example, the type of ceiling insulation, external cladding[14] or the concrete specification in the foundation does not affect the thermal assessment results significantly; however, these choices do affect the life cycle assessment results so are included in the LCA results section.

The results of the thermal assessment are presented below in Table 27 and Table 28 which for each option shows the NatHERs Star rating, cooling loads, heating loads and the total cooling and heating loads. The results for each group are discussed in more detail below.

[14] The difference in R value between fibre cement and timber cladding is less than 0.01 m^2K/W (Australian Government Department of the Environment and Energy 2019)

Table 27 Thermal assessment star ratings results for both single brick and timber internal walls for each wall type

Option	Item	Star rating	
		Single Leaf Internal Brick Walls	Timber Frame Internal Walls
Wall Structures	Base Case Design	5.4	5.4
Wall Structures	Base Case Design (with R1.3 cavity insulation)	6.7	6.4
Wall Structures	Hempcrete	6.9	6.3
Wall Structures	Timber frame	6.6	6.2
Wall Structures	Steel frame	6.6	6.2
Wall Structures	Strawbale infill	7.1	6.4
Wall Structures	SIPS	6.9	6.3
Wall Structures	Timber frame reverse brick veneer	7.2	6.8

Table 28 Thermal assessment results for the Base Case design and Design Options (default assumptions)

Grouping	Item	Star rating	Cooling Loads ($MJ/m^2/y$)	Heating Loads ($MJ/m^2/y$)	Total Cooling and Heating Loads ($MJ/m^2/y$)
Base case	Base Case Design	5.4	3.4	94.4	97.8
Wall Structures	Base Case Design (with R1.3 cavity insulation)	6.7	7.9	62.7	70.6
	Hempcrete	6.3	13.7	63.5	77.2
	Timber frame	6.2	14.2	65.6	79.8
	Steel frame	6.2	14.2	65.6	79.8
	Strawbale infill	6.4	13.1	58.7	71.8
	SIPS	6.3	15.6	60.2	75.8
	Timber frame reverse brick veneer	6.8	11.4	54.3	65.7
Windows	Aluminium (no thermal break) - 6mm Single Glazed Low-E	5.6	4.8	89.1	93.9
	Aluminium (no thermal break) - Double glazed	5.8	2.8	87	89.8
	Timber - Single glazing	5.4	2.7	95	97.7
	Timber - 6mm Single Glazed Low-E	5.4	2.2	98.5	100.7
	Timber - Double glazed	5.9	2.2	82	84.2
	uPVC - Single glazing	5.4	2.7	95	97.7
	uPVC - 6mm Single Glazed Low-E	5.4	2.2	98.5	100.7
	uPVC - Double glazed	5.9	2.3	82.2	84.5
	Aluminium (thermal break) - Double glazed	5.7	2.4	87.9	90.3
Flooring (Living Areas)	Marmoleum / Linoleum	5.4	3.4	94.6	98
	Cork	5.4	5.3	95.3	100.6
	Timber (directly glued to concrete slab)	5.4	5.3	95.3	100.6
	Polished Concrete (Slab)	5.4	3.4	94.7	98.1
Flooring (Bedrooms)	Wool Carpet	5.4	3.4	94.7	98.1
	Timber (directly glued to concrete slab)	5.4	3.3	94.5	97.8
Foundation	Insulated slab edges (XPS)	5.4	4.7	94.2	98.9

3.1.1 Design options

3.1.1.1 Walls

The thermal assessment results for the default Base Case Design and wall Design Options are presented in Figure 8. Note that the Base Case Design includes concrete rendered double brick exterior walls (no cavity insulation) and plaster render single brick interior walls. The default interior walls for the Design Options are all timber frame with insulation and painted plasterboard either side.

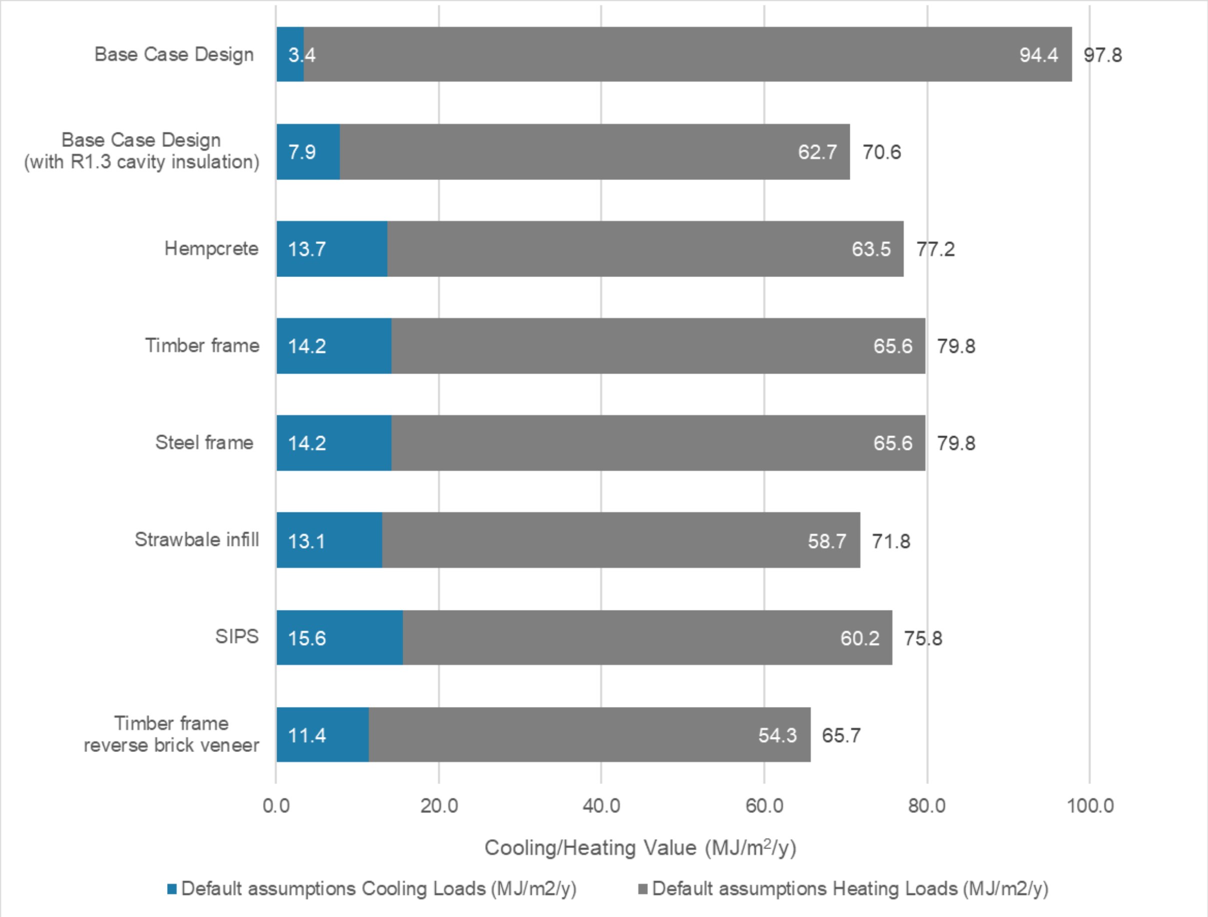

Figure 8 Thermal assessment results for the Base Case design and wall Design Options (default assumptions). Labels for cooling loads, heating loads, and totals are shown.

The wall option with the best thermal performance is the Timber frame reverse brick veneer followed by the insulated double brick with cavity insulation and strawbale infill; however, the insulated double brick walls with cavity insulation also include internal brick walls. When each of the wall design options is set to use single leaf brick internal walls, the benefit of having interior thermal mass becomes apparent – see Figure 9 below.

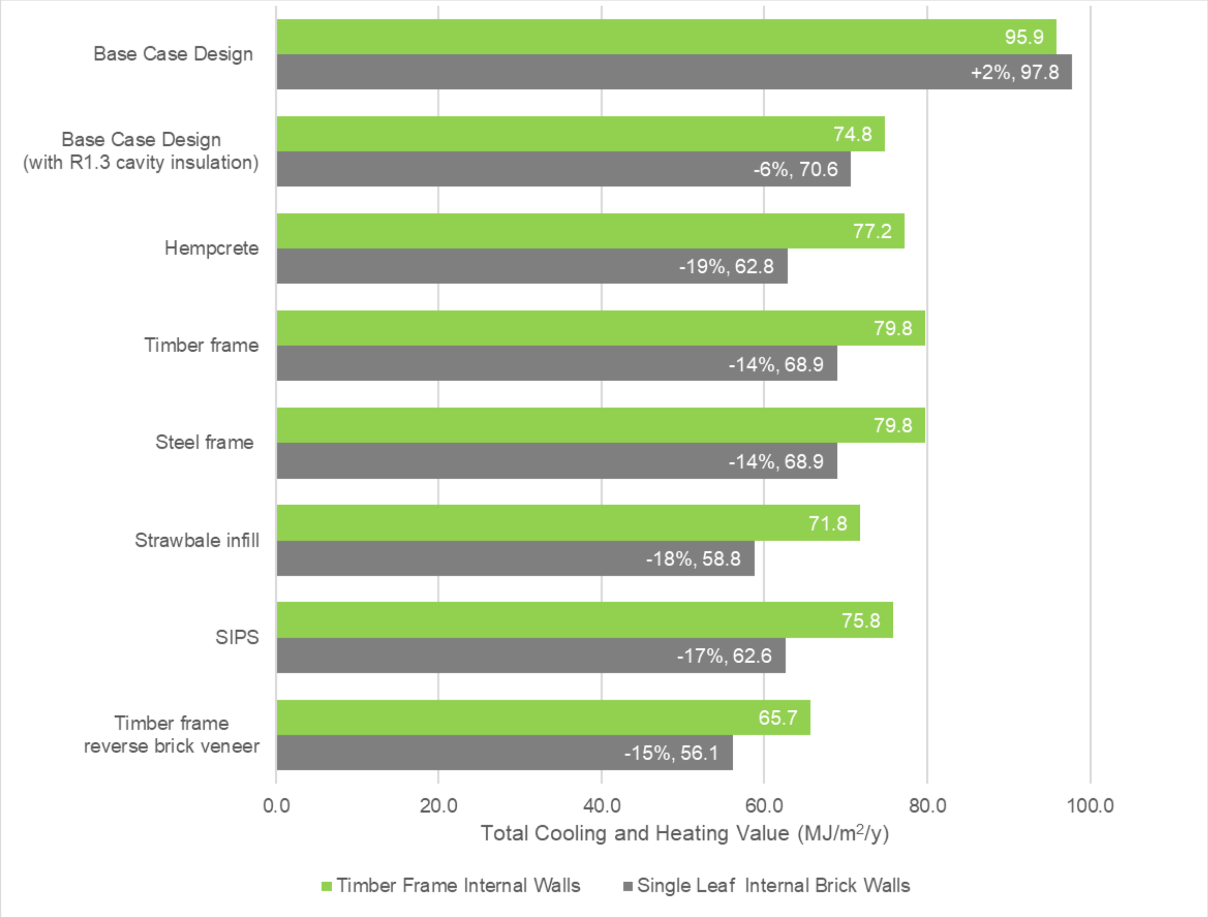

Figure 9 Thermal results for timber and single leaf internal brick walls (difference shown as a percentage)

As shown in Figure 9, all wall Design Options can reduce the total cooling and heating loads by increasing the thermal mass of internal walls. The wall Design Options with the best thermal performance with internal brick walls are: Timber frame reverse brick veneer, strawbale (infill), SIPS, and hempcrete. The options with the lowest thermal performance are the Base Case Design and the Base Case Design with cavity insulation.

Note that these results only include the thermal assessment results and exclude the full life cycle (embodied impacts) – the results for the full life cycle are presented in section 3.2.

3.1.1.2 External cladding

The thermal modelling software did not show any difference in the choice of external cladding on timber frame walls so have not been presented. There are differences in the LCA results which are presented in section 3.2.

3.1.1.3 Windows

The thermal performance of the window Design Options is presented below in Figure 10.

The double-glazed windows achieved the best thermal performance. The timber and uPVC double glazed windows were the highest performing overall. The window type with the lowest thermal performance was the Timber and uPVC single glazed low-E, however, that it should be noted that this assessment assumed that all windows in the house were of the same type throughout. The use of low-E windows on the northern side of the building will block heat from passively warming the house, which leads to higher heating loads and lower cooling loads. The best thermal performance would more than likely be achieved with a mix of the window frame and glazing types appropriately chosen for each part of the house. This emphasises the need for individual thermal assessments on each dwelling (as per government requirements) so that the thermal performance of the building can be optimised.

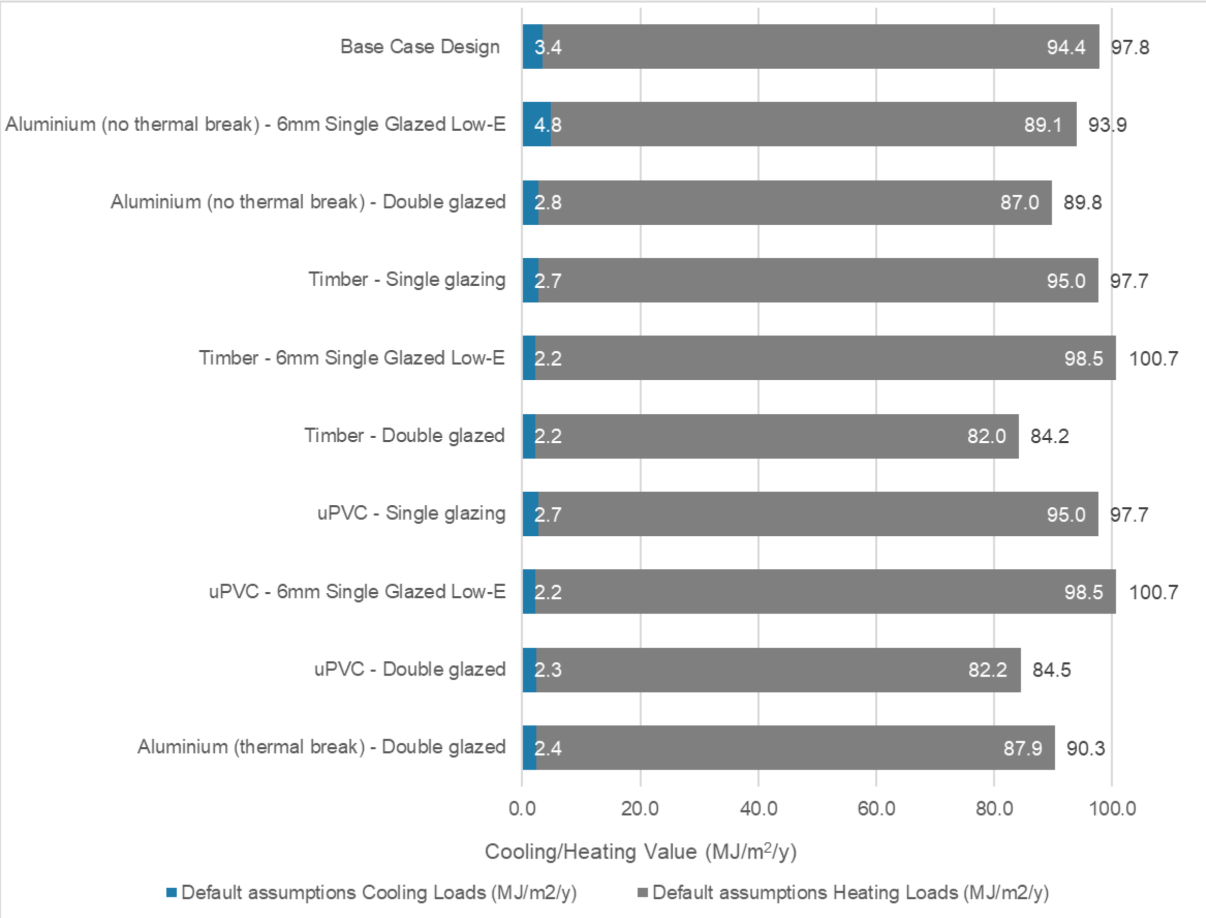

Figure 10 Thermal assessment results for the Base Case design and window Design Options. Labels for cooling loads, heating loads, and totals are shown.

3.1.1.4 Ceiling insulation

The thermal modelling software did not show any difference in the choice of the type of ceiling insulation as long as they are specified to the same insulation value (R6.0).

3.1.1.5 Flooring – living areas and bedrooms

The thermal results for the Base Case Design and living area flooring design options are shown below in Figure 11. Note that the Base Case Design assumes tiled floors in the living areas (lounge, dining and kitchen) and nylon carpets in the bedrooms.

The thermal results for different flooring options show similar performance with cork and timber[15] requiring slightly higher cooling and heating loads than the other options.

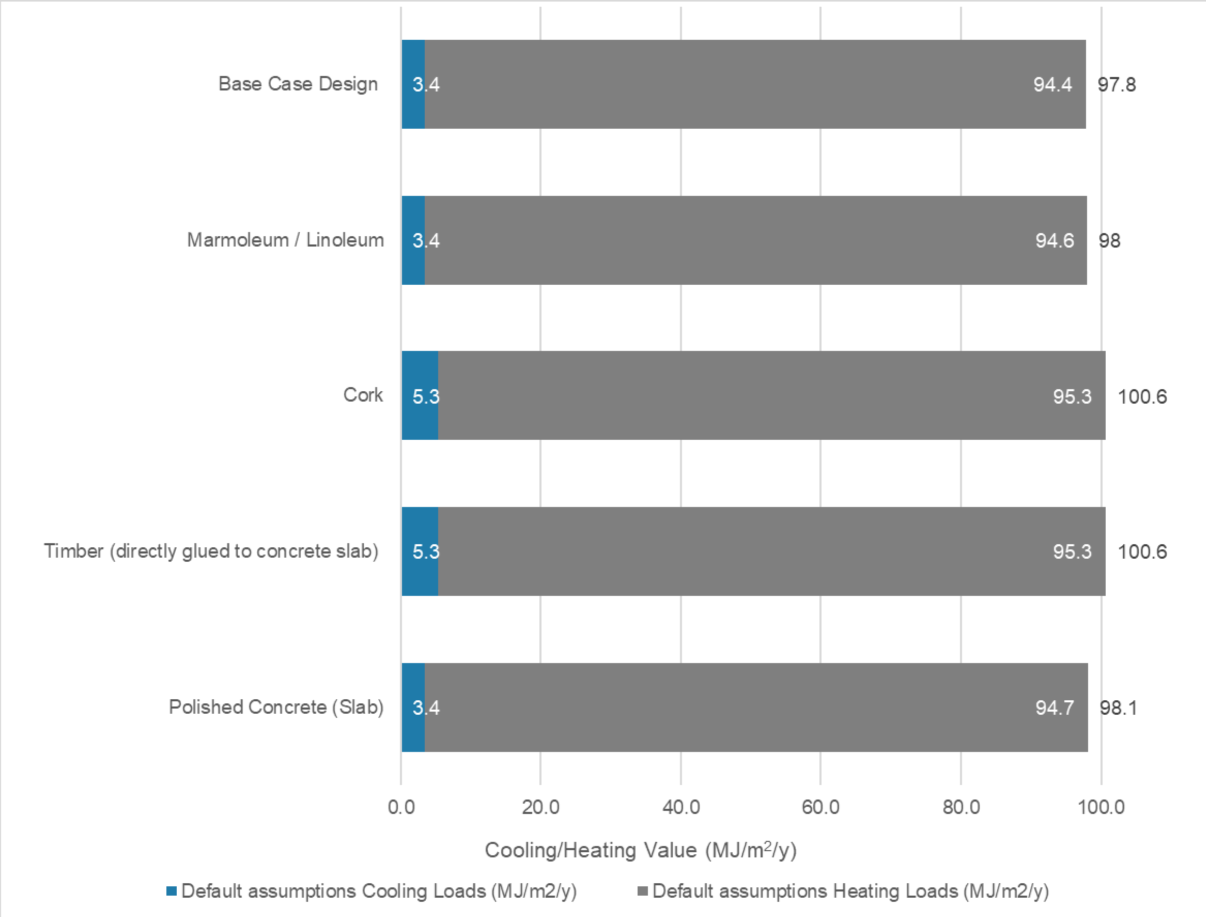

Figure 11 Thermal assessment results for the Base Case design and living area flooring Design Options. Labels for cooling loads, heating loads, and totals are shown.

The thermal results are very similar for the bedroom flooring Design Options (see Figure 12 below).

[15] Note that Timber and cork use the same model in the thermal assessment software

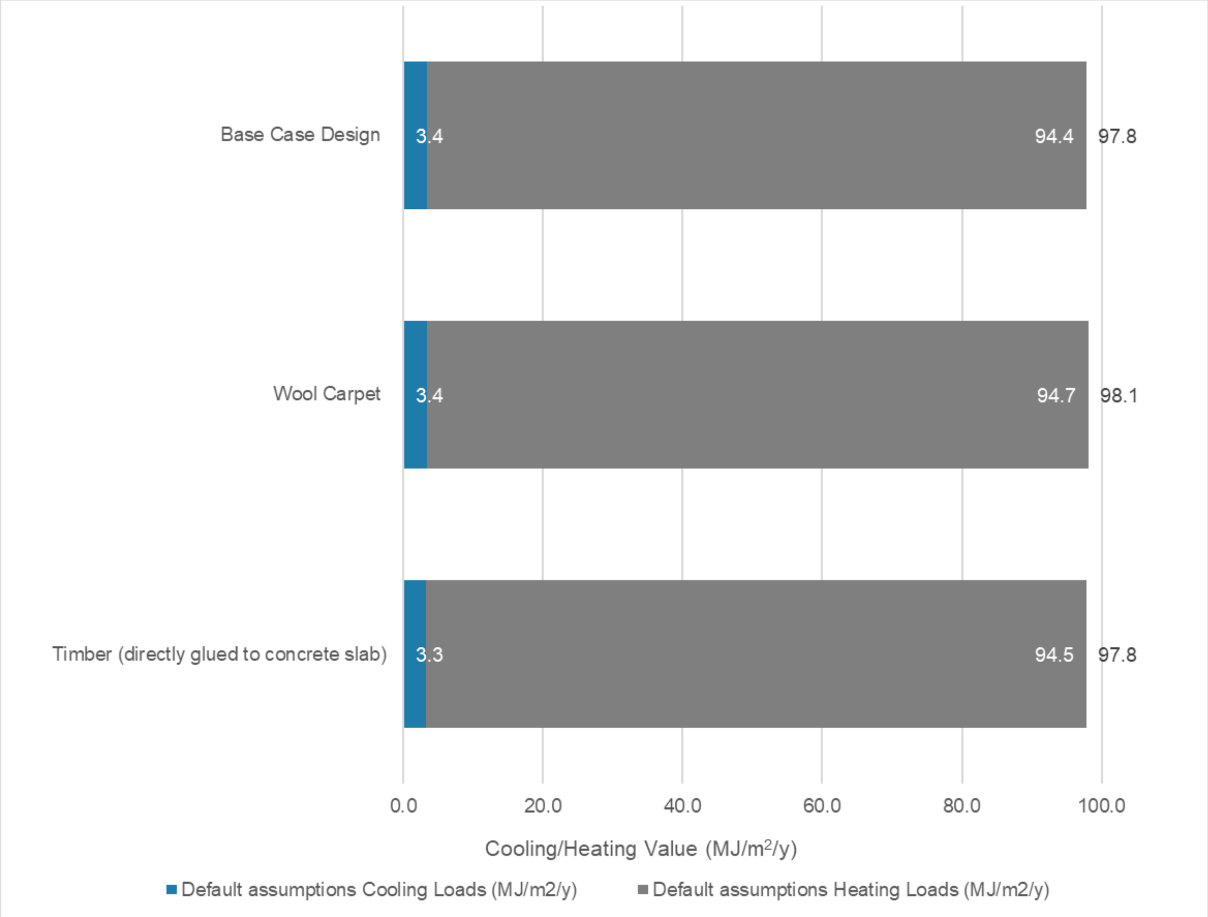

Figure 12 Thermal assessment results for the Base Case design and bedroom area flooring Design Options. Labels for cooling loads, heating loads, and totals are shown.

3.1.1.6 Foundations

The foundation options investigated include the use of eco (extended) concrete and insulated slab edges. The use of eco (extended) concrete does not affect the thermal results, and the use of insulated slab edges on this dwelling design leads to slightly higher total cooling and heating loads compared to an uninsulated slab edge (Figure 13). Therefore, for the Witchcliffe climate, insulated slab edges do not perform as well thermally as uninsulated slab edges.

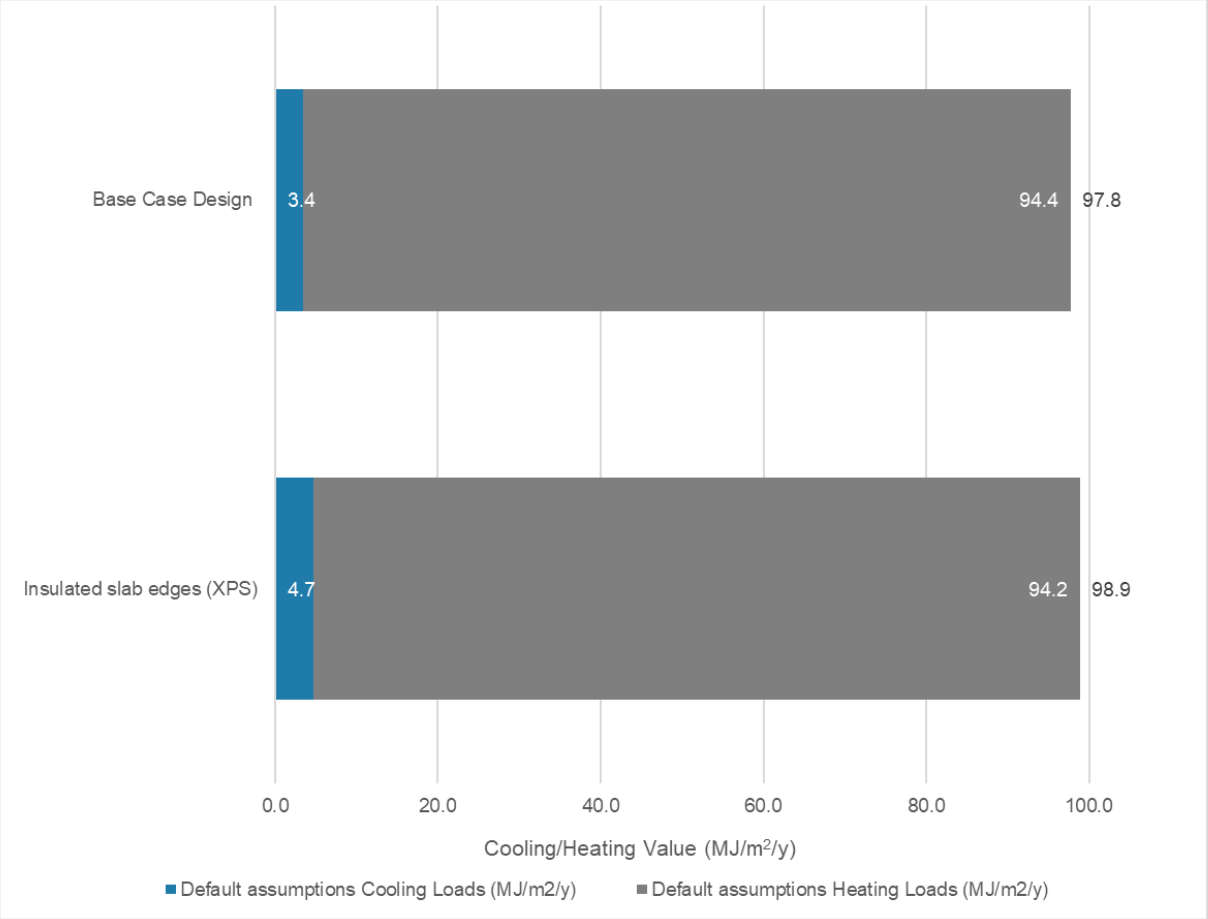

Figure 13 Thermal assessment results for the Base Case design and foundation Design Options. Labels for cooling loads, heating loads, and totals are shown.

3.2 LIFE CYCLE ASSESSMENT

This section presents the results over the whole life cycle of the dwelling. Results are presented for the Base Case Design and all design options focussing on Global Warming Potential (GWP) – also referred to as the carbon footprint. The results for six other environmental impact indicators are also presented to identify hotspots and minimise potential burden shifting between environmental impact indicators:

- Ozone depletion potential (ODP) – the release of ozone layer damaging substances
- Acidification potential (AP) – emissions that produce acid rain
- Eutrophication potential (EP) – emissions that lead to nutrient pollution and algal blooms
- Photochemical ozone creation potential (POCP) – emissions that contribute to summer smog
- Abiotic depletion potential – elements (ADPE) – extraction of mineral resources
- Abiotic depletion potential – fossil fuels (ADPF) – extraction of fossil fuels

Please refer to Table 4 for further descriptions of the environmental impact indicators.

The results are presented on a whole of building basis to enable like-for-like comparisons between design options to be made. For example, a 5% reduction in GWP for wall option “A” is equivalent to a 5% reduction for floor type “F”.

3.2.1 Base case design

The Base Case Design without a solar PV system would have a carbon footprint of 566,000 kg CO_2e, which includes emissions associated with the materials and energy, over the 80-year predicted service life of the dwelling (Figure 14). Installing a 6.6 kWp solar PV system (shown in Figure 14 as ‘Base Case Design v2’), with no other changes, would result in the carbon footprint over the life of the building[16] to be -47,800 kg CO_2e.

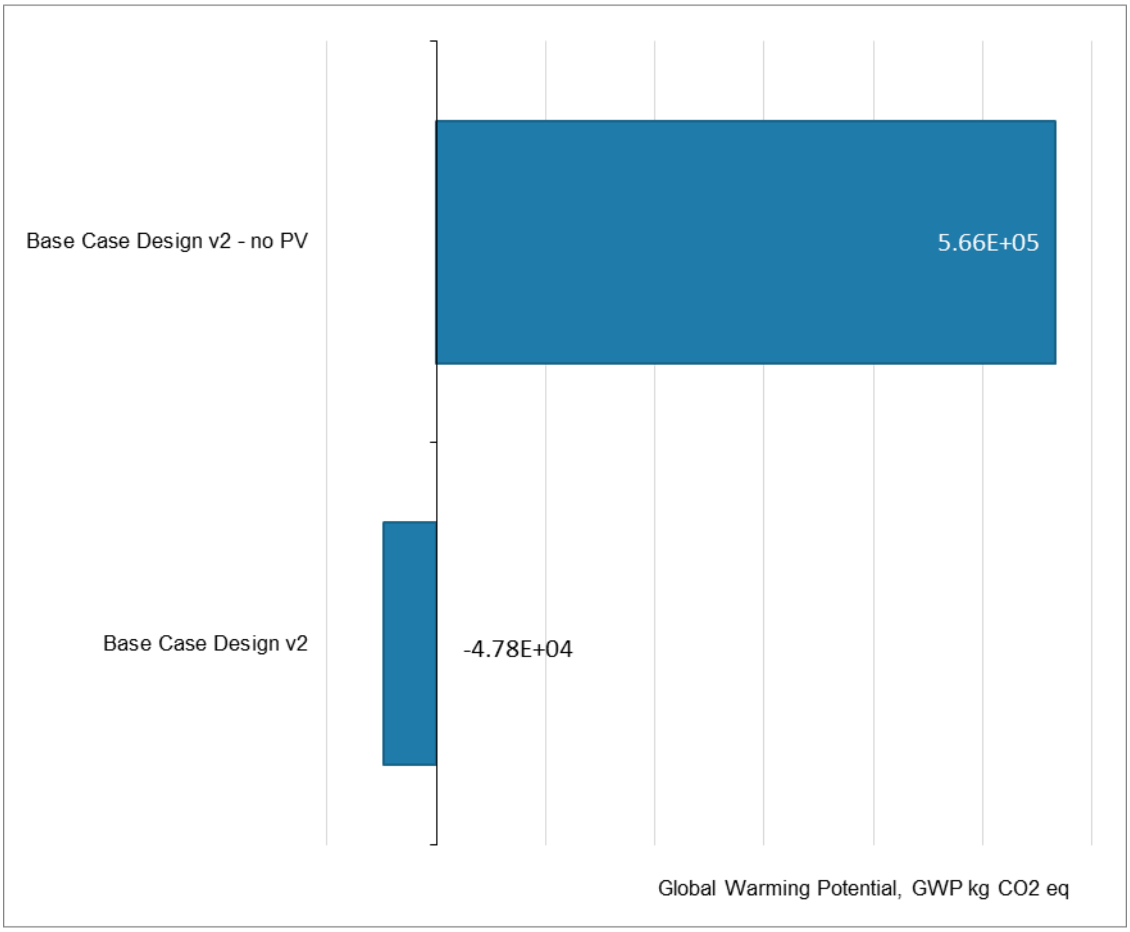

Figure 14 Global warming potential results for Base Case Design - no PV and Base Case Design (with solar PV)

[16] Compared to electricity supplied from the grid (WA SWIS). See Electricity grid mix section for details.

Table 29 Relative LCIA results for Base Case Design (no solar PV) and Base Case Design (with solar PV)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Base Case Design v2 - no PV	+1284%	-4%	+116%	+89%	+29%	-57%	+777%

The results for the other indicators (Table 29) show a similar pattern (as the consumption of fossil fuels consumed to produce electricity) are reduced. The exception to this is Abiotic depletion of elements (ADPE) and Ozone depletion (ODP) which are both lower for the Base Case Design without PV. Rich Haynes has explained these counter-intuitive results (2019) as:

> The high levels of ADP/ODP associated with PV systems are the result of Tantalum (an unusually rare mineral) in the inverter capacitors. It is likely a combination of the following:
>
> - An incorrect assumption about the mass of inverters the background database (particularly for large systems). The base assumption is 10kg of inverter mass per kW of the solar system; however, this figure has been reduced significantly over time.
> - An incorrect / out of date background LCI inventory data: Tantalum capacitors have been largely replaced by polymer capacitors in inverters. So potentially this is not an issue although it is difficult to confirm this with inverter manufacturers. Fronius did confirm that they do not use Tantalum capacitors in their inverters.
> - An incomplete inventory for other electronics in the building (meaning the benchmark is not complete, hence the increase associated with the inverters looks like a big increase, but it would not be if we had all the electronics in the building.

Performing corrections on the solar PV inverter mass from 10 kg/kWh to 17.5 kg/5 kW inverter (SMA Solar Technology AG 2019) does slightly reduce the ADPE (from -57% to -43%) and ODP (from -4% to -3%), however, the results for these impact categories are still higher for the Base Case Design that includes solar PV.

In conclusion, the significant decreases in the majority of the impact categories (GWP, AP, EP, POCP and ADPF) should not be overlooked by smaller increases in other impact categories (ADPE and ODP). ADPE impacts can be further reduced by ensuring that valuable substances are recycled (the current modelling assumes that the inverters are disposed of in landfill) and choosing inverters that have a long product life (the current assumption is that the inverters last ten years). Life cycle information should also be requested from equipment manufacturers to ensure that they are aware of – and actively taking steps to reduce – the environmental impacts of the products that they produce.

3.2.1.1 Hotspots in the Base Case Design

The GWP hotspots in the Base Case Design are shown below in Figure 15. Note that the figure excludes the electricity produced by the solar PV system – appliances and equipment that consume electricity are presented individually to provide insight into their contribution.

The majority of the GWP impact associated with the hotspot items can be addressed through the use of solar electricity which supports the focus of the design team. However, the consumption of electricity, whether from onsite solar or the grid, reduces the net benefit from electricity exported as exported solar electricity displaces electricity that would otherwise be produced from fossil fuels. Therefore, it is important to use appliances and equipment that are as energy-efficient as possible, to minimise electricity consumption, in addition to the use of solar PV systems.

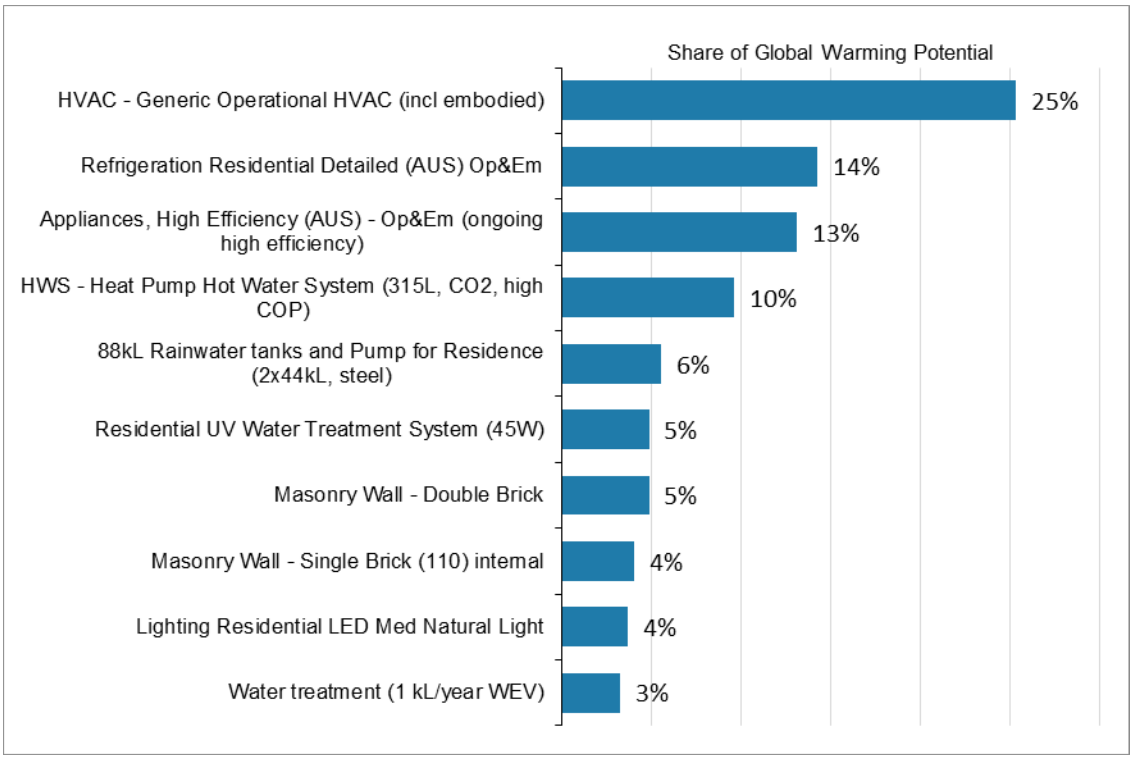

Figure 15 GWP hotspots in the Base Case Design

The figure shows that the largest hotspots in the Base Case Design are the HVAC/air-conditioning system with 25% (34% of which are from refrigerant losses), refrigerator electricity consumption (14%), electricity consumption of other appliances (even though high-efficiency appliances have been assumed to be used) and the heat pump hot water system.

HVAC

The study assumes the use of an air-conditioning system with COP/EER of 3.0 and R410a refrigerant. Refrigerant leakage rates were calculated following the Methods of Calculating Total Equivalent Warming Impact (TEWI) from the Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH 2012). The electricity consumption of the dwelling can be reduced further through the use of high-efficiency air-conditioning units (COP values greater 3.0). The use of low GWP refrigerant gases (e.g. R744 CO_2) can also significantly reduce GWP emissions over the life of the dwelling and should be recommended to homeowners.

Refrigerator-freezers

The study uses average energy usage statistics for typical refrigerators and freezers are used in Australian homes to provide context for the results. The electricity consumption of average Australian refrigerators and freezers (Richard Haynes 2019) used in the modelling are:

- 588 kWh/year for the primary refrigerator-freezer – MEPS 2 star fridge/freezer with total volume of 500 L (Energyratings.gov.au 2019)
- 214 kWh/year allowance for a secondary refrigerator
- 268 kWh/year allowance for a separate freezer.

Significant reductions in electricity consumption of refrigerators and freezers can be achieved through the use of higher efficiency appliances. For example, a typical MEPS 4-star unit of comparable size to the primary refrigerator-freezer listed above would consume 40% less (356 kWh/year[17]) than a MEPS 2-star unit. It is recommended that the Design Guidelines provide information to homeowners on the benefits of using high-efficiency refrigerators and freezers.

Rainwater tanks, pumps, and UV treatment

The supply of rainwater totals 11% of the GWP (tanks, pump, and UV treatment). As previously indicated in Table 9, the electricity consumption of the UV water sterilisation unit (394 kWh/year) can be higher than the electricity consumption of the water pressure pump (268 kWh/year). The UV water sterilisation units commonly available operate the UV bulb continuously, rather than only when water is being consumed (Davey 2017). As the demand for rainwater tank UV sterilisation units increases it is expected that the energy efficiency of these units will also improved through the use of advanced control systems.

The assumption for the electricity consumption of the water pressure pump is that it consumes 2.0 kWh/kL (Richard Haynes 2019). Hauber-Davidson and Shortt (2011) and

[17] (Energyratings.gov.au 2019)

Amaro (2012) measured the in-use power consumption across a range of domestic water plumbing applications typical to use of rainwater and recorded values from 0.4 to 2.4 kWh/kL. General conclusions from these water pump studies were:

- In-use power consumption can vary in real-world applications from 0.4 to 2.4 kWh/kL depending on the pump choice and installation design
- In-use power consumption decreases as the flow rate increases
- In-use power consumption for filling toilets can vary by almost three times (1.5 to 4.3 kWh/kL) depending on the type of float valve used in the toilet cistern

The electricity consumption associated with the rainwater system could be reduced significantly based on the pump choice and installation design.

Wall types

The masonry bricks (double and single) in the Base Case Design contribute 9% in total to the GWP which supports the design teams focus on the selection of external and internal walls used in the buildings. Choice of wall type is further investigated below in section 3.2.2.1.

3.2.2 Design Options

The following section discusses the LCA results for the different Design Options assessed.

When interpreting the results, it is important to keep in mind that the base case scenario - against which the different design options are compared - already includes a 6.6 kW solar PV system (as this is a requirement for all dwellings in the village). This means that:

- **Results are negative (e.g. the carbon footprint of the base case design is -47,800 kg CO2e over the study period). The design options with the lowest values have lower impacts for each impact category.**
- **Percentage difference in results compared to the base case scenario are larger than they would be if the base case scenario was a typical dwelling that didn't use solar PV and instead consumed electricity from the grid.**
- **The results of this study only valid for the scope as outlined within this report and may not be indicative of or applicable to other circumstances.**

3.2.2.1 Wall types

The LCA results for the different external wall options are presented below in Figure 16 and Table 30. Note that these results are for the default assumptions for internal wall type – single brick internal walls for the Base Case Design and timber frame internal walls for the other designs.

The GWP results are similar for all external wall type design options (Figure 16) – all have significantly lower GWP compared to the Base Case Design. The results show that the Timber frame reverse brick veneer and SIPS (no ERV) have the lowest GWP results closely followed by Timber frame walls Steel frame, Straw bale (infill) with lime render, and Hempcrete. Additional scenarios have been modelled to investigate these results and optimise designs further.

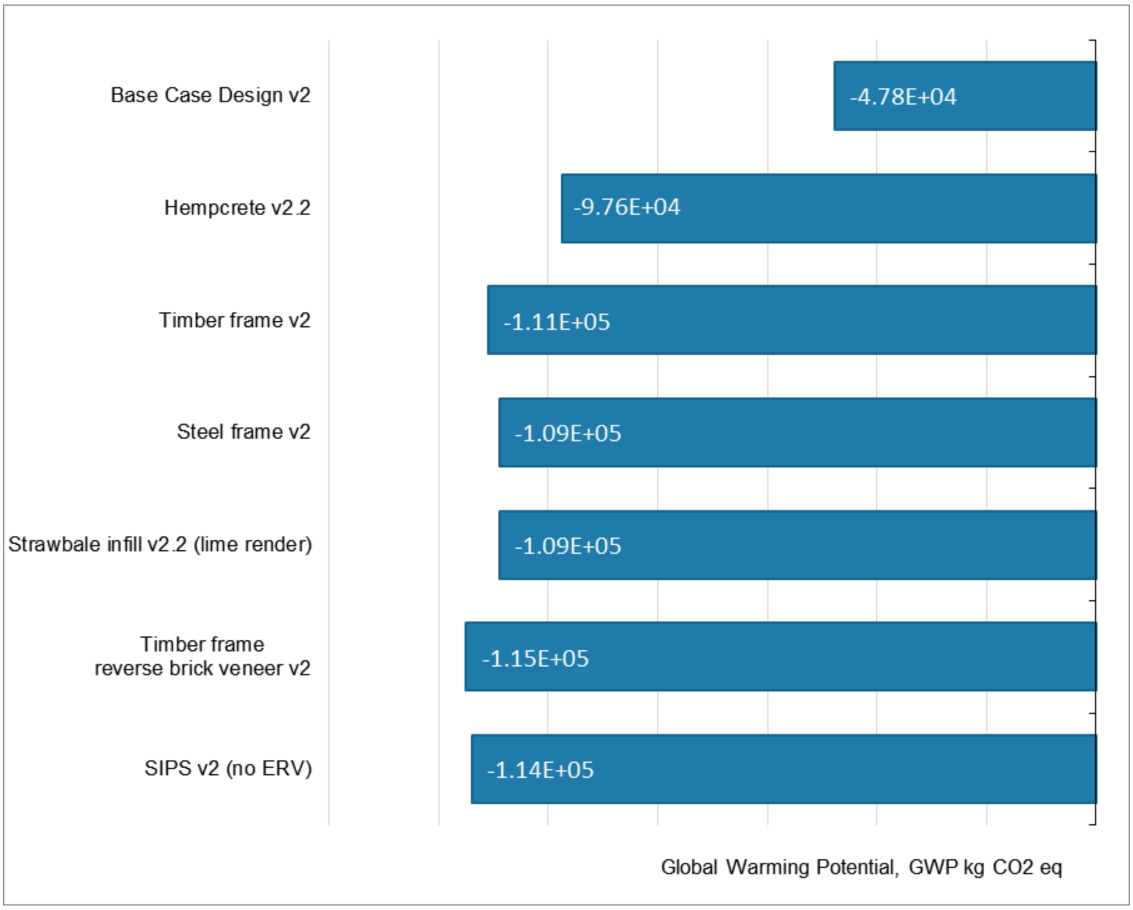

Figure 16 Global warming potential results for Base Case Design and Design Options for external walls (default assumptions)

The relative results for the other environmental impact categories (Table 30) show reductions compared to the Base Case Design and do not indicate any significant burden shifting between environmental impact categories.

Table 30 Relative LCIA results for external wall Design Options compared to the Base Case Design (double brick)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Hempcrete v2.2	-104%	-5%	-11%	-6%	-4%	-1%	-43%
Timber frame v2	-132%	-8%	-18%	-10%	-5%	-0%	-51%

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Steel frame v2	-128%	-8%	-18%	-10%	-7%	-0%	-51%
Strawbale infill v2.2 (lime render)	-128%	-7%	-13%	-8%	-5%	-0%	-50%
Timber frame reverse brick veneer v2	-141%	-8%	-17%	-11%	-4%	-0%	-60%
SIPS v2 (no ERV)	-139%	-7%	-17%	-10%	+1%	-0%	-51%

Hempcrete

The GWP hotspots in the Hempcrete wall system are the production of the lime and the assumption that hydrated lime (calcium hydroxide) and hemp shiv are transported from Europe (see LCI section for further details). The sensitivity analysis on the transport demonstrated that if the hemp and lime could be produced locally (see transport distance assumptions in Table 15) the GWP of the hempcrete wall system could be reduced by 11% on whole building basis (see Figure 17). Potential environmental impacts for the other environmental impact categories would also be lower (Table 31).

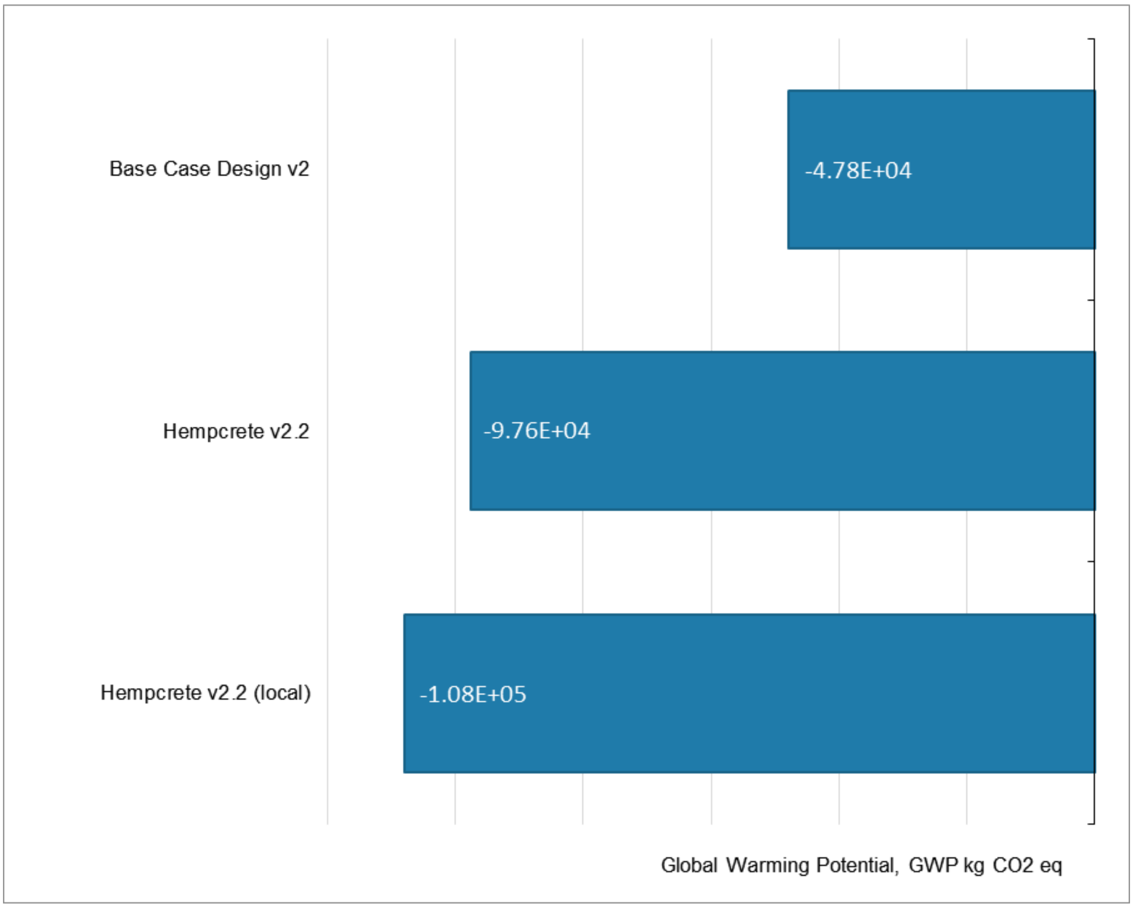

Figure 17 Hempcrete GWP sensitivity analysis to transport distances

Table 31 Relative LCIA results for Hempcrete external wall Design Options compared to the Base Case Design (double brick)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Hempcrete v2.2 (Europe)	-104%	-5%	-11%	-6%	-4%	-1%	-43%
Hempcrete v2.2 (local)	-126%	-7%	-18%	-11%	-6%	-1%	-56%

Timber frame

Several additional timber frame scenarios were investigated to achieve further GWP reductions – the results are presented in Figure 18. The timber frame wall system with the lowest GWP was the Timber frame with reverse mud-brick veneer and mud-brick internal walls. The building with Timber frame with mud-brick internal walls also had a lower carbon footprint than the timber frame with reverse brick veneer external walls (light weight brick) and timber internal walls. The GWP results demonstrate that further improvements can be made by increasing the thermal mass inside the buildings where the internal mass also has low embodied carbon (e.g. mud-bricks).

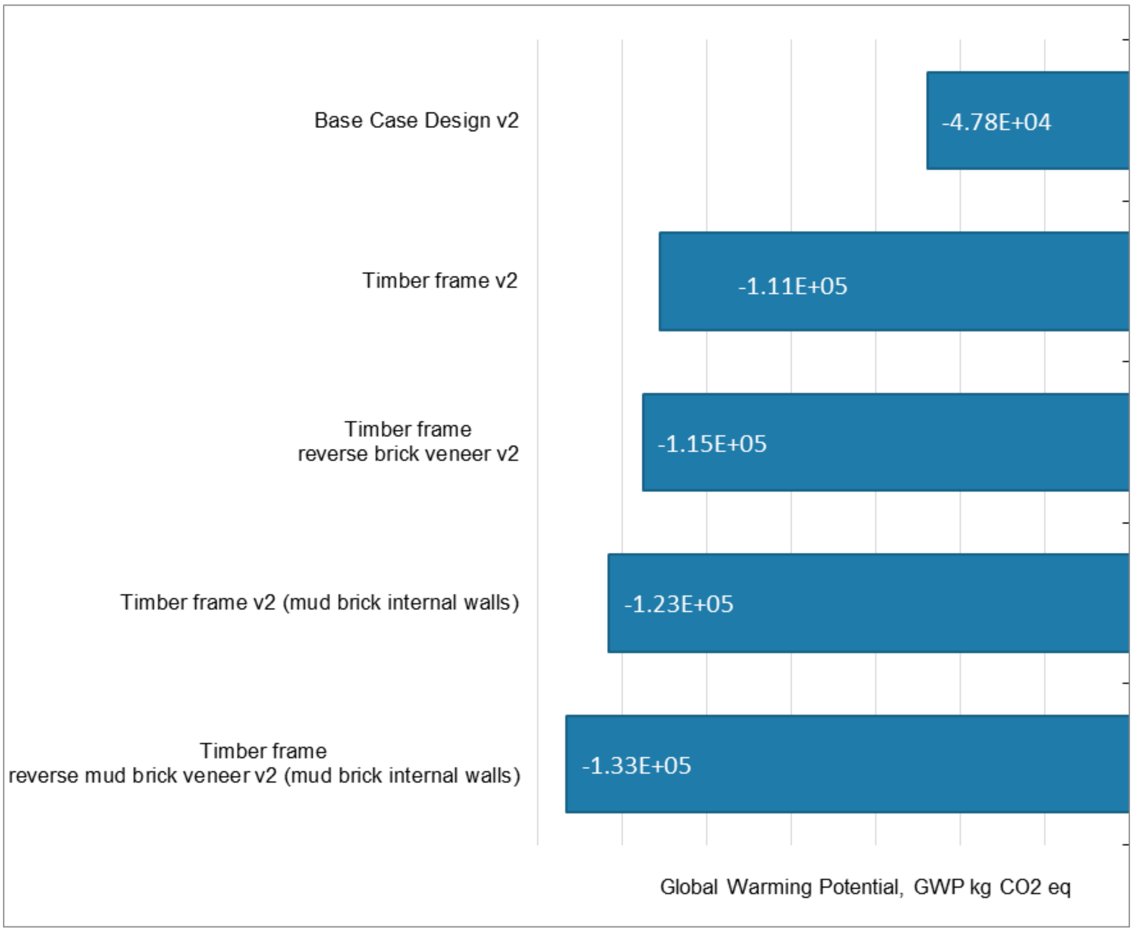

Figure 18 Global warming potential results for Timber frame and Timber frame reverse brick veneer Design Options for external walls

Table 32 Relative LCIA results for Timber frame and Timber frame reverse brick veneer external wall Design Options compared to the Base Case Design (double brick)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Timber frame v2	-132%	-8%	-18%	-10%	-5%	-0%	-51%
Timber frame reverse brick veneer v2	-141%	-8%	-17%	-11%	-4%	-0%	-60%
Timber frame v2 (mud-brick internal walls)	-157%	-9%	-22%	-13%	-10%	-1%	-74%
Timber frame reverse mud-brick veneer v2 (mud-brick internal walls)	-178%	-8%	-23%	-14%	-10%	-1%	-85%

Straw bale

Straw bale options were investigated further to determine which Design Options would result in the lowest carbon footprint (GWP) buildings (Figure 19). The results indicate that using clay render and clay internal bricks would result in the lowest carbon footprint of all of the wall design options investigated (-1.37E+05 kg CO_2e). Straw bale walls with clay render also had a lower GWP than straw bale with hydrated lime (calcium hydroxide) render due to the embodied GWP associated with the lime production.

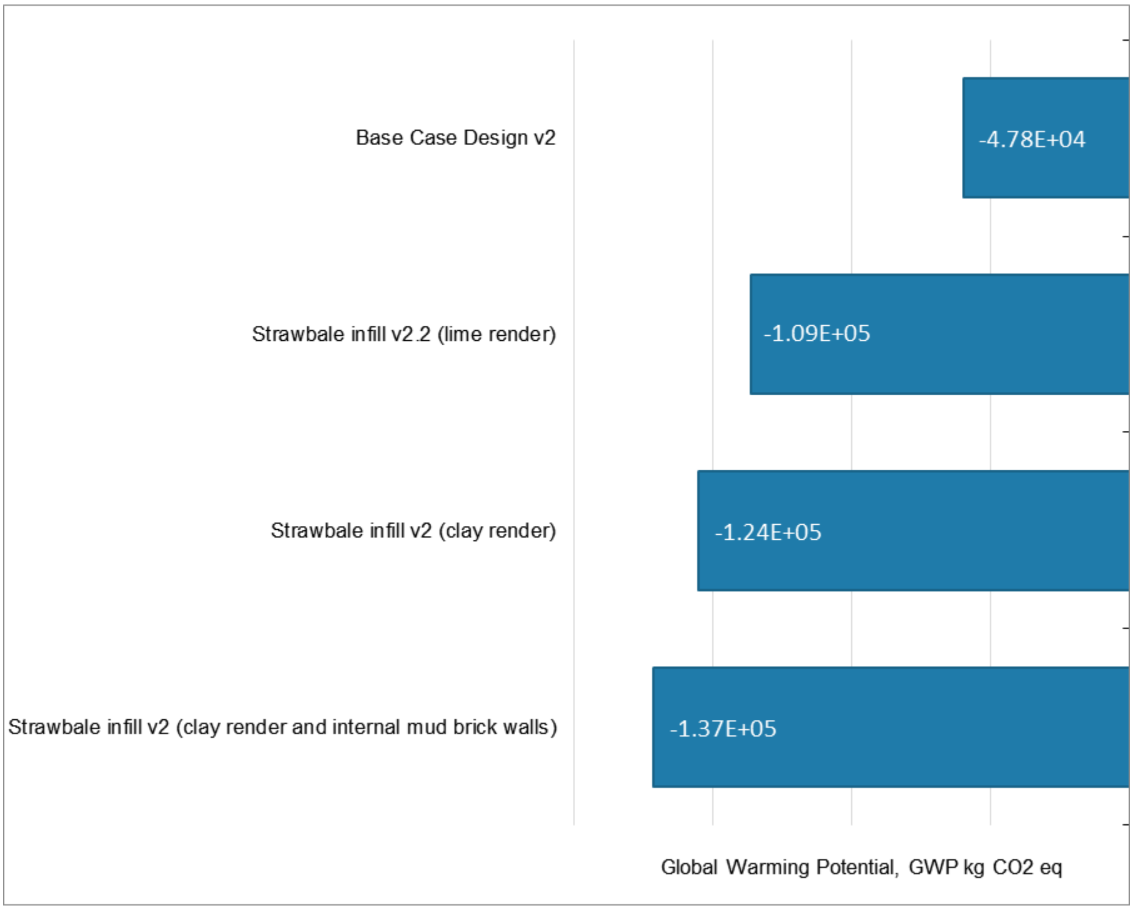

Figure 19 Global warming potential results for Straw Bale Design Options for external walls

Table 33 Relative LCIA results for Straw Bale external wall Design Options compared to the Base Case Design (double brick)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Strawbale infill v2.2 (lime render)	-128%	-7%	-13%	-8%	-5%	-0%	-50%
Strawbale infill v2 (clay render)	-159%	-8%	-19%	-11%	-8%	-1%	-63%
Strawbale infill v2 (clay render and internal mud-brick walls)	-187%	-8%	-23%	-14%	-14%	-2%	-86%

SIPS

The use of SIPS walls with and without the inclusion of an ERV unit was investigated. The results, compared to the Base Case Design, are shown below in Figure 20.

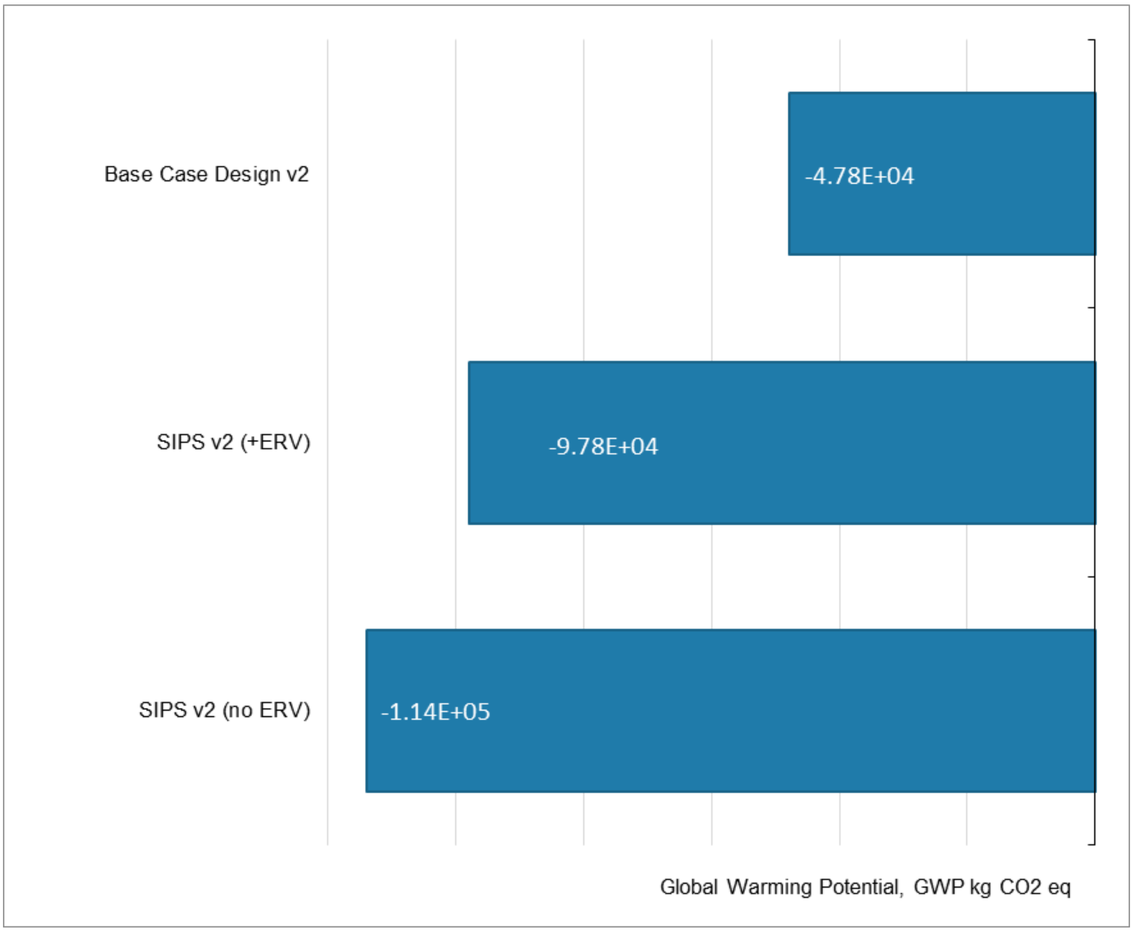

Figure 20 Global warming potential results for SIPS with and without ERV compared to Base Case Design (double brick)

Table 34 Relative LCIA results for SIPS external walls compared to the Base Case Design (double brick)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
SIPS v2 (+ERV)	-105%	-7%	-13%	-6%	+2%	-0%	-31%
SIPS v2 (no ERV)	-139%	-7%	-17%	-10%	+1%	-0%	-51%

The ERV unit was assumed to be operated using carbon dioxide (occupancy) sensors to reduce the electricity consumption, however, in a high-efficiency dwelling, the addition of any other electrical loads decreases the amount of electricity that can be exported to the grid. This leads to higher GWP, as shown in Figure 20. The results for the SIPs external wall type, even when including the use of an ERV, have significantly lower GWP (and most other environmental impact indicators) compared to the Base Case Design.

Note that none of the other wall Design Options includes the use of an ERV, however, due to the airtight nature of many of the options, ERVs may need to be considered to ensure that the dwellings are adequately ventilated to provide fresh air and to reduce internal condensation levels.

Conclusions for Wall Design Options

The conclusions from the assessment of wall Design Options are:

- The results for all wall Design Options were significant improvements over the Base Case Design with GWP reductions of between -98% to -187%.
- The wall Design Options with the lowest carbon footprints overall (including additional scenarios) were:
  - Strawbale infill with clay render and internal mud-brick walls (-187% compared to the Base Case Design)..
  - Timber frame with reverse mud-brick veneer and mud-brick internal walls (-178% compared to the Base Case Design).
- Increasing the internal thermal mass of all Design Options through the use of clay brick (or even lightweight brick) lead to better thermal performance and lower greenhouse gas emissions over the life cycle of the building.
- The use of ERV units in SIPS buildings does result in a slightly higher carbon footprint (compared to a SIPs building without an ERV unit) due to electricity consumption. Due to the airtight nature of many of the wall types, ERV units may need to be considered to ensure adequate ventilation. Where used, ERVs should be controlled using automatic occupancy sensors (e.g. carbon dioxide sensors) to reduce electricity consumption as much as possible.

3.2.2.2 External cladding

The results comparing the use of fibre cement external cladding with timber cladding are presented below in Figure 21 and Table 35. Both cladding options are compared, assuming Timber frame wall construction. The results indicate that the use of fibre cement cladding leads to a small increase in GWP by 6% over the life cycle of the dwelling compared to timber cladding. The results for the other environmental indicators do not change significantly. Both the timber cladding and fibre cement cladding are significantly lower than the double brick Base Case Design with -132% and -118%, respectively (Figure 21).

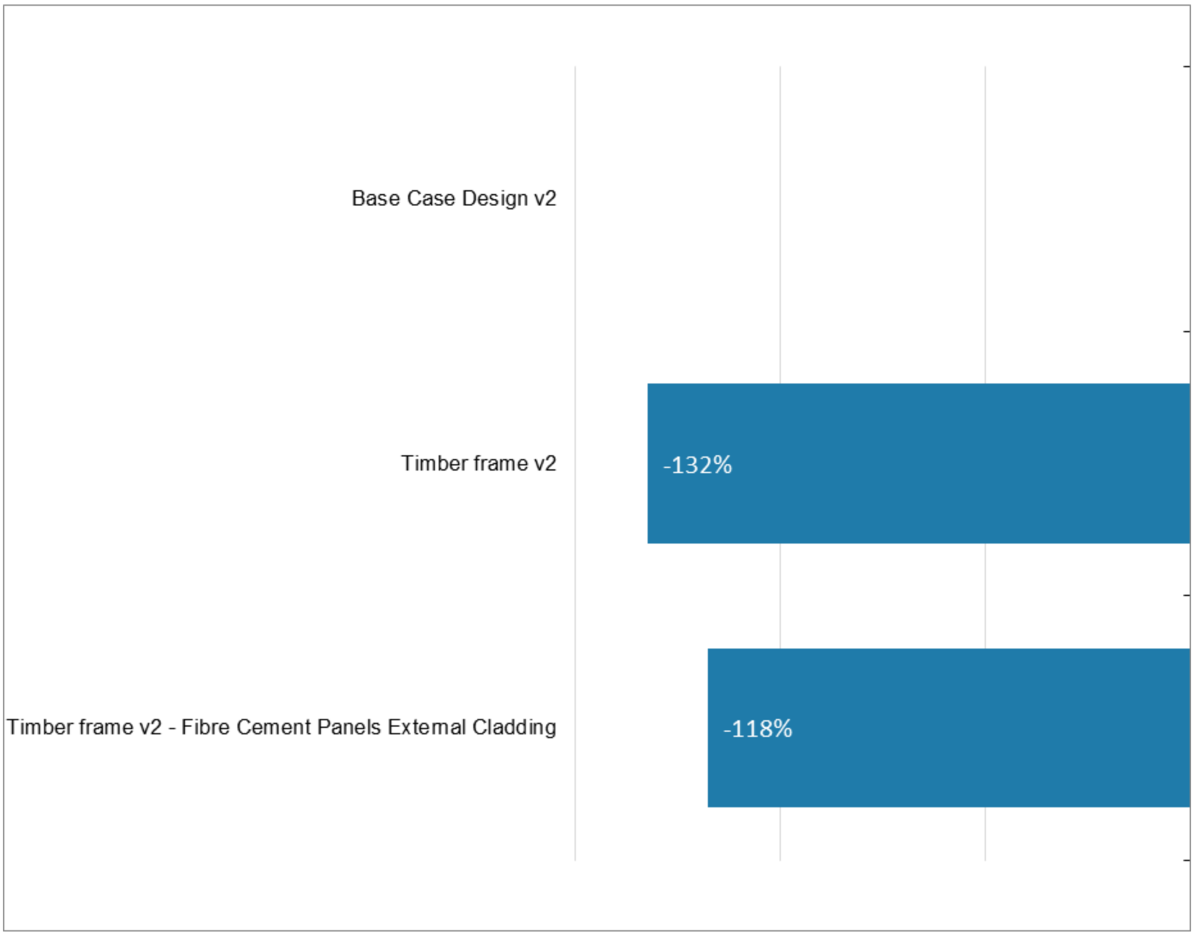

Figure 21 Global warming potential for fibre cement and timber external cladding compared to the Base Case Design

Table 35 Relative LCIA results for fibre cement external cladding Design Options compared to the Timber frame with timber cladding

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Timber frame v2 - Fibre Cement Panels External Cladding	+6%	+0%	+1%	+1%	-1%	0%	0%

3.2.2.3 Windows

The relative LCA results for the window design options investigated are presented below in Figure 22 and Table 36. Both the Timber and uPVC double glazed windows have the lowest GWP results (-33%) followed by aluminium double-glazed windows (both with and without thermal breaks).

Despite Timber and uPVC single glazed windows having a similar thermal performance to the Aluminium single glazed windows (in the Base Case Design, see Figure 10), the GWP results for Timber and uPVC are lower[18] than the aluminium.

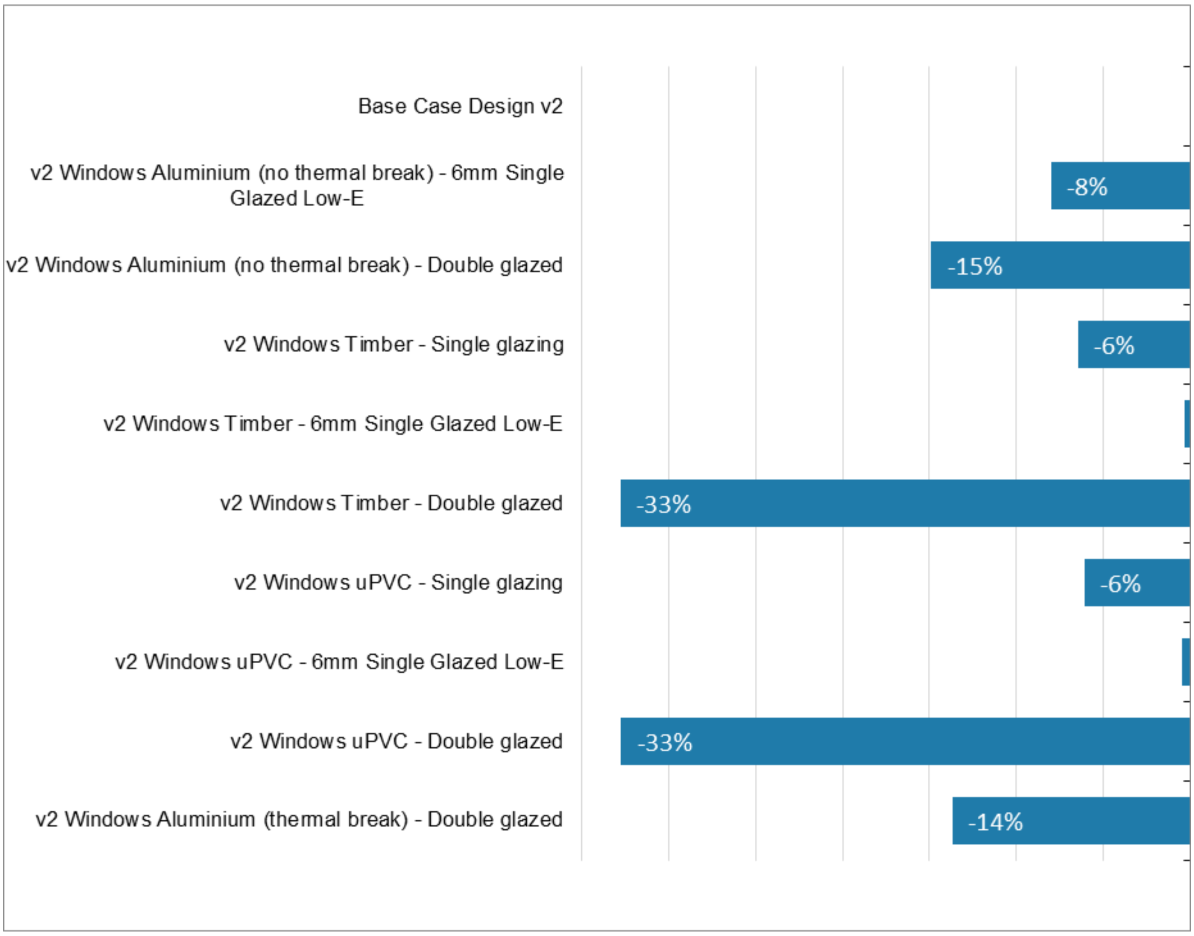

Figure 22 Relative Global warming potential results for window Design Options compared to the Base Case Design (single glaze aluminium frame)

Table 36 Relative LCIA results for window Design Options compared to the Base Case Design (single glaze aluminium frame)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
v2 Windows Aluminium (no thermal break) - 6mm Single Glazed Low-E	-8%	0%	-1%	-1%	-0%	-0%	-5%
v2 Windows Aluminium (no thermal break) - Double glazed	-15%	0%	-1%	-1%	-0%	0%	-9%
v2 Windows Timber - Single glazing	-6%	0%	-2%	-0%	-1%	-0%	-2%
v2 Windows Timber - 6mm Single Glazed Low-E	-0%	0%	-2%	+0%	-1%	-0%	+1%
v2 Windows Timber - Double glazed	-33%	-0%	-5%	-3%	-2%	-0%	-18%

[18] Presumably this is due to the GWP associated with the aluminium frames, however, the LCA model for windows does not provide results data at this level.

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
v2 Windows uPVC - Single glazing	-6%	-0%	-2%	-0%	-2%	-0%	-1%
v2 Windows uPVC - 6mm Single Glazed Low-E	-0%	-0%	-2%	0%	-2%	-0%	+2%
v2 Windows uPVC - Double glazed	-33%	-0%	-5%	-3%	-3%	-0%	-17%
v2 Windows Aluminium (thermal break) - Double glazed	-14%	0%	-1%	-1%	-0%	0%	-8%

3.2.2.4 Ceiling insulation

The results for all ceiling insulation types were all very similar except for the results for wool insulation which was significantly higher (see Figure 23 and Table 37 below). Except for wool insulation, greater reductions in environmental impacts can be achieved through the use of more insulation (between R4.0 and R6.0), than can be achieved through the choice of the type of insulation.

The wool insulation had the highest GWP compared to other insulation types, so the results were verified against other sources to confirm the validity of the findings. The eToolLCD database had a corrected[19] GWP factor of 20 kg CO_2e/kg for wool which was found to be slightly more conservative than other references listed below.

- 21.3 kg CO2-e/kg wool (Wiedemann et al. 2016)
- 24.9 kg CO2-e per kg of greasy wool at the farm gate (Brock et al. 2013).

The GWP results for wool are dominated by the enteric methane emissions from the sheep, which account for 79 to 89% of the GWP emissions associated with the production of wool (Wiedemann et al. 2016).

The rigid polystyrene had slightly higher GWP (+8%) and ADPF (11%) results than the Base Case Design (rock/mineral wool), however, due to the closed nature of the material it may be easier to clean and reuse at the end-of-life of the ceilings[20] compared to the other insulation batt types that have open fibres.

[19] The original GWP for wool insulation in the eToolLCD database (Australasian LCI v13 – Life Cycle Strategies) was 60 kg CO_2e/kg wool.
[20] The base assumption for ceiling insulation is that it would be replaced at the 50 year end-of-life of the ceilings (Rawlinsons 2011).

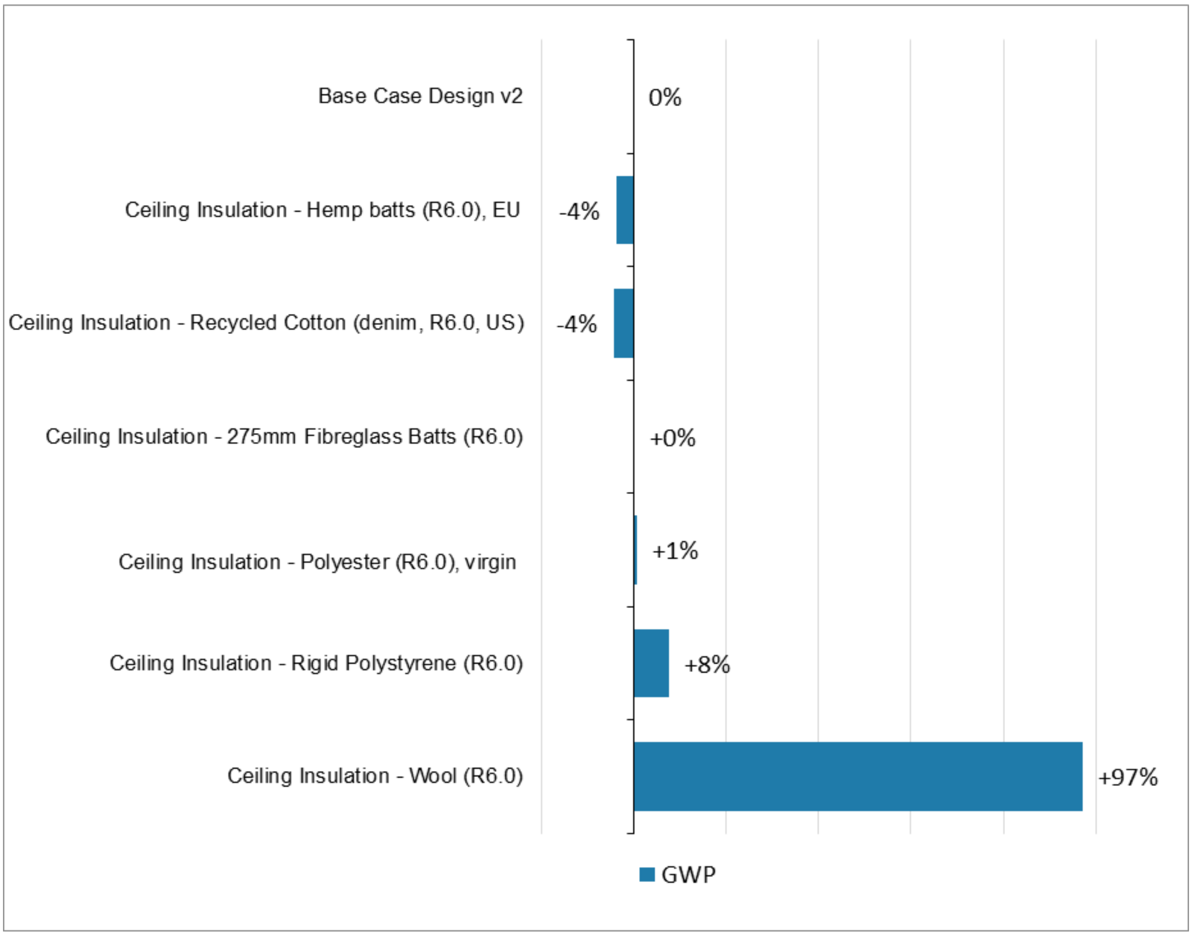

Figure 23 Relative Global warming potential results for ceiling insulation Design Options compared to the Base Case Design (rockwool)

Table 37 Relative LCIA results for ceiling insulation Design Options compared to the Base Case Design (rockwool)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Ceiling Insulation - Hemp batts (R6.0), EU	-4%	+0%	+0%	+1%	+0%	-1%	+3%
Ceiling Insulation - Wool (R6.0)	+97%	+0%	+105%	+115%	+20%	+0%	+5%
Ceiling Insulation - Recycled Cotton (denim, R6.0, US)	-4%	+0%	+0%	+1%	+1%	-1%	+2%
Ceiling Insulation - 275mm Fibreglass Batts (R6.0)	+0%	0%	0%	0%	+0%	0%	0%
Ceiling Insulation - Polyester (R6.0), virgin	+1%	0%	-1%	-0%	+0%	-1%	+4%
Ceiling Insulation - Rigid Polystyrene (R6.0)	+8%	0%	+1%	0%	+17%	-1%	+11%

3.2.2.5 Flooring – living areas and bedrooms

The GWP results for the choice of flooring in the living areas (Figure 24) indicate that the Marmoleum/Linoleum and Timber have similar results with a 7% reduction compared to the Base Case Design which assumed the use of floor tiles.

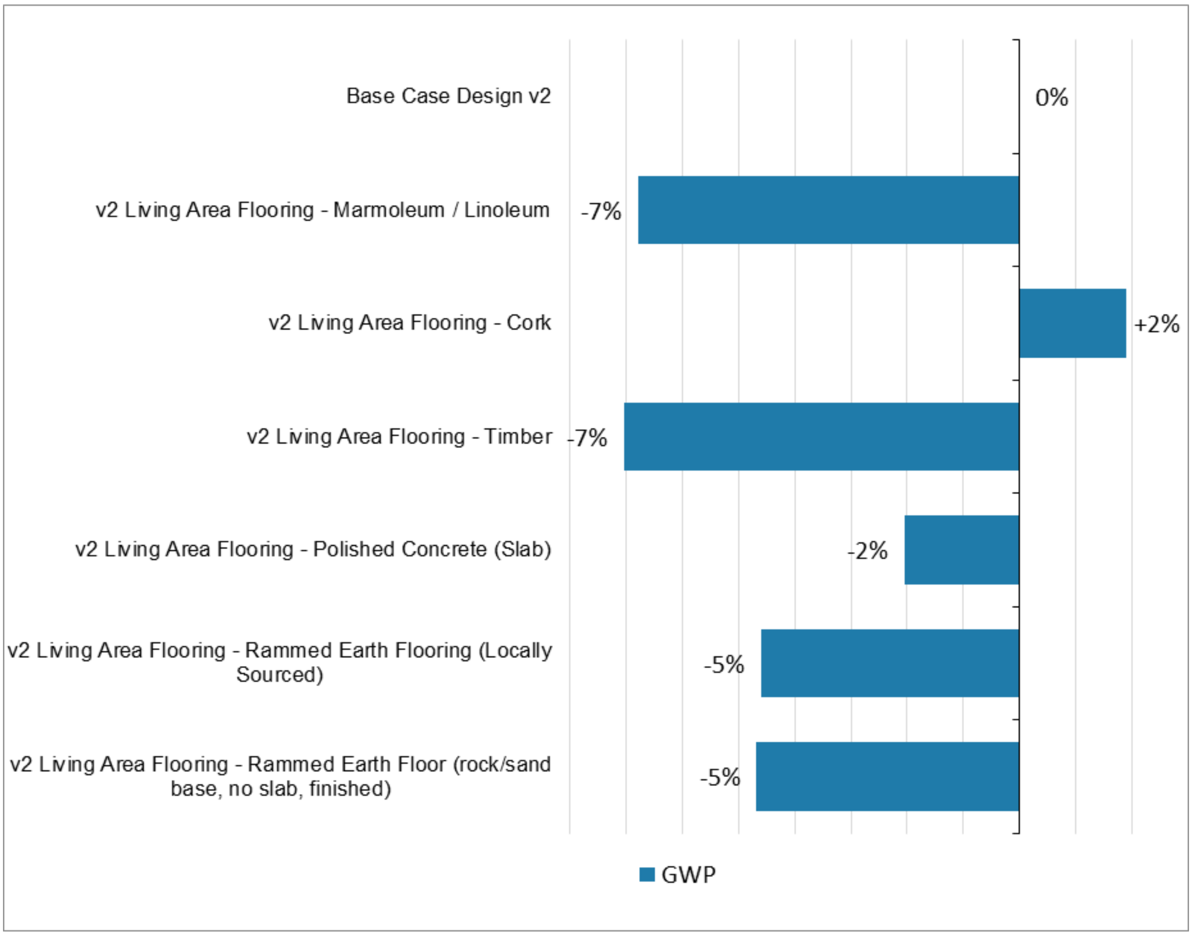

Figure 24 Relative Global warming potential results for living area flooring Design Options compared to the Base Case Design (tile)

Rammed earth floors gave a 5% reduction and there was little difference between whether the earth floor was installed on top of the concrete slab or directly onto a rock and sand base. Where the earth floor was installed directly on the ground, additional concrete foundations (perimeter footing beams) were required for the walls, which, along with the need for rock and sand for the base[21] of the earth wall, meant there was little difference in the results overall.

The other flooring types were not significantly different (+/-2%) from the Base Case Design.

[21] For the earth floor on rock/sand base, the only materials that were not used (compared to the concrete slab) were cement and water

Note that the assumption for the Polished Concrete flooring Design Option it was assumed that the floor finish was 'grind and seal' with the surface sealed with polyurethane coating. It was assumed that the floor coating is re-applied every 10 years (eTool Pty Ltd 2019). Alternative final finish options for polished concrete flooring, including acid etch, industrial finish and premium low-maintenance finishes (CCC Polished Concrete 2019), have not been investigated and may have slightly different LCA results.

The results for the choice of bedroom flooring are shown below in Figure 25 and Table 38. Similar to the results for wool insulation, the wool carpet results[22] are higher than the Base Case assumption (nylon carpet). Both datasets assume the same average lifespan of 10 years (eTool Pty Ltd 2019) which is in line with guarantee periods of wool carpet manufacturers such as Godfrey Hirst (Godfrey Hirst 2019).

Note that differences in cleaning methods of the floor types have been excluded as it has been assumed that a vacuum cleaner has been used on all floor types (as included in Appliances template). The use of a broom on hard floors (instead of a vacuum cleaner) would only slightly reduce the electricity consumption (1.3 kWh/m^2/year[23]), over the life of the building.

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[22] The results for wool carpet have not been corrected and remain those as per the eToolLCD database (eTool Pty Ltd 2019)

[23] Daily vacuuming (7 days/week) once per day, 1000W vacuum cleaner, 279 m^2/hour cleaning productivity rate (British Cleaning Council 2010), = 1.31 kWh/m^2/year.

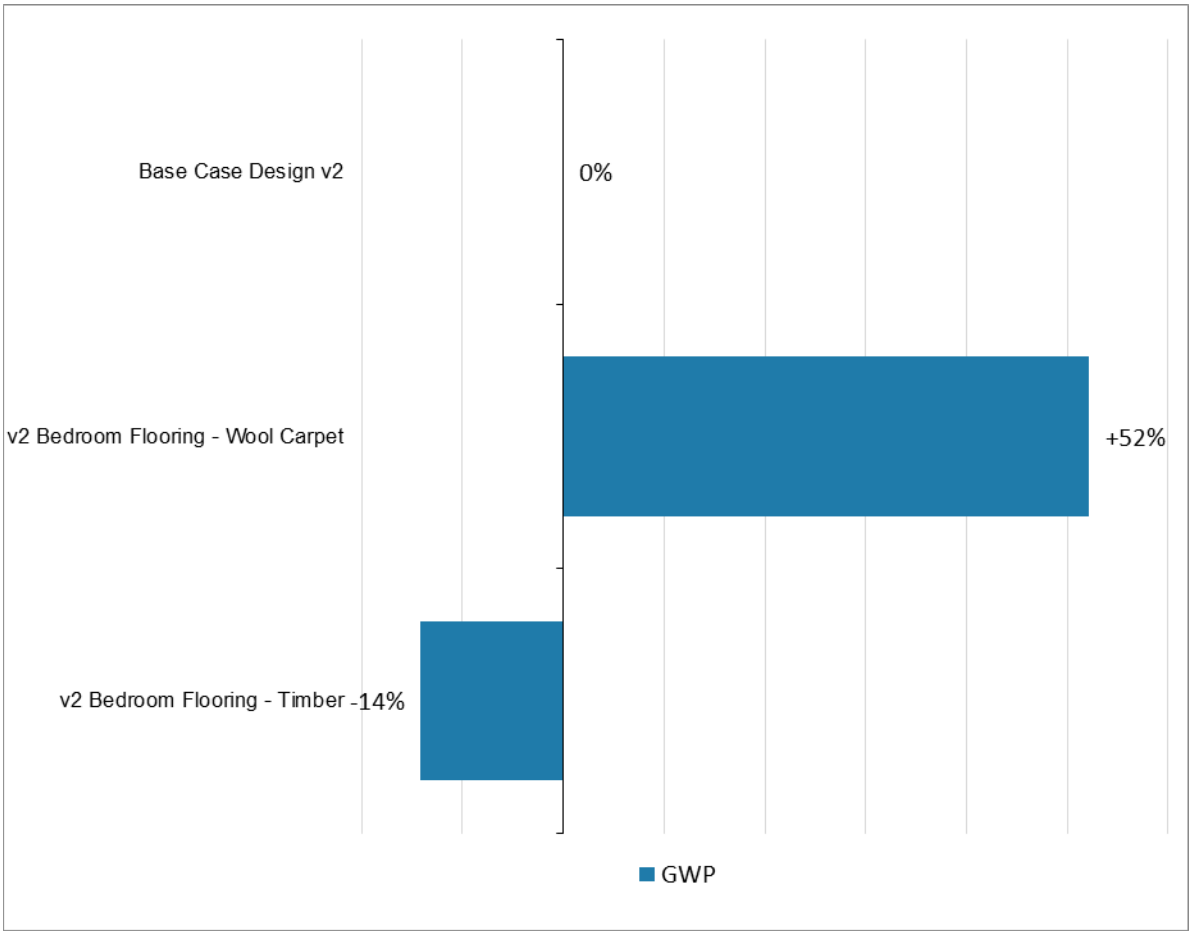

Figure 25 Relative Global warming potential results for bedroom flooring Design Options compared to the Base Case Design (nylon carpet)

Table 38 Relative LCIA results for living room flooring Design Options compared to the Base Case Design (tile)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
v2 Living Area Flooring - Marmoleum / Linoleum	-7%	-0%	-2%	-1%	-1%	-1%	-3%
v2 Living Area Flooring - Cork	+2%	-0%	+0%	+0%	+1%	-0%	+3%
v2 Living Area Flooring - Timber	-7%	0%	+0%	0%	+3%	-0%	+2%
v2 Living Area Flooring - Polished Concrete (Slab)	-2%	-0%	-0%	-0%	+1%	-1%	+1%
v2 Living Area Flooring - Rammed Earth Flooring (Locally Sourced)	-5%	-0%	-1%	-1%	-0%	-0%	-2%
v2 Living Area Flooring - Rammed Earth Floor (rock/sand base, no slab, finished)	-5%	0%	-1%	0%	-2%	-0%	-2%

Table 39 Relative LCIA results for bedroom flooring Design Options compared to the Base Case Design (nylon carpet)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
v2 Bedroom Flooring - Wool Carpet	+52%	+0%	+52%	+57%	+9%	+0%	+4%
v2 Bedroom Flooring - Timber	-14%	-0%	-1%	-1%	+1%	-2%	-6%

3.2.2.6 Foundations

The results of the Design Options for foundations are presented below in Figure 26 and Table 40. The use of extended (eco) concrete[24] such as 30% fly ash can reduce the GWP by 3%. Fly ash is a reclaimed product that is collected from the flue stacks of coal-fired power stations using an electrostatic precipitator. It is locally available in WA from the Collie power station and is processed by Boral.

Insulated slab edges lead to slightly higher total thermal loads (see Figure 13), which, in addition to higher embodied impacts associated with the use of expanded foam, lead to slightly higher impacts over the life cycle compared to the Base Case Design (with no insulated slab edges). Therefore, insulated slab edges are not recommended for the Cottage Lot Design.

[24] also known as supplementary cementitious materials

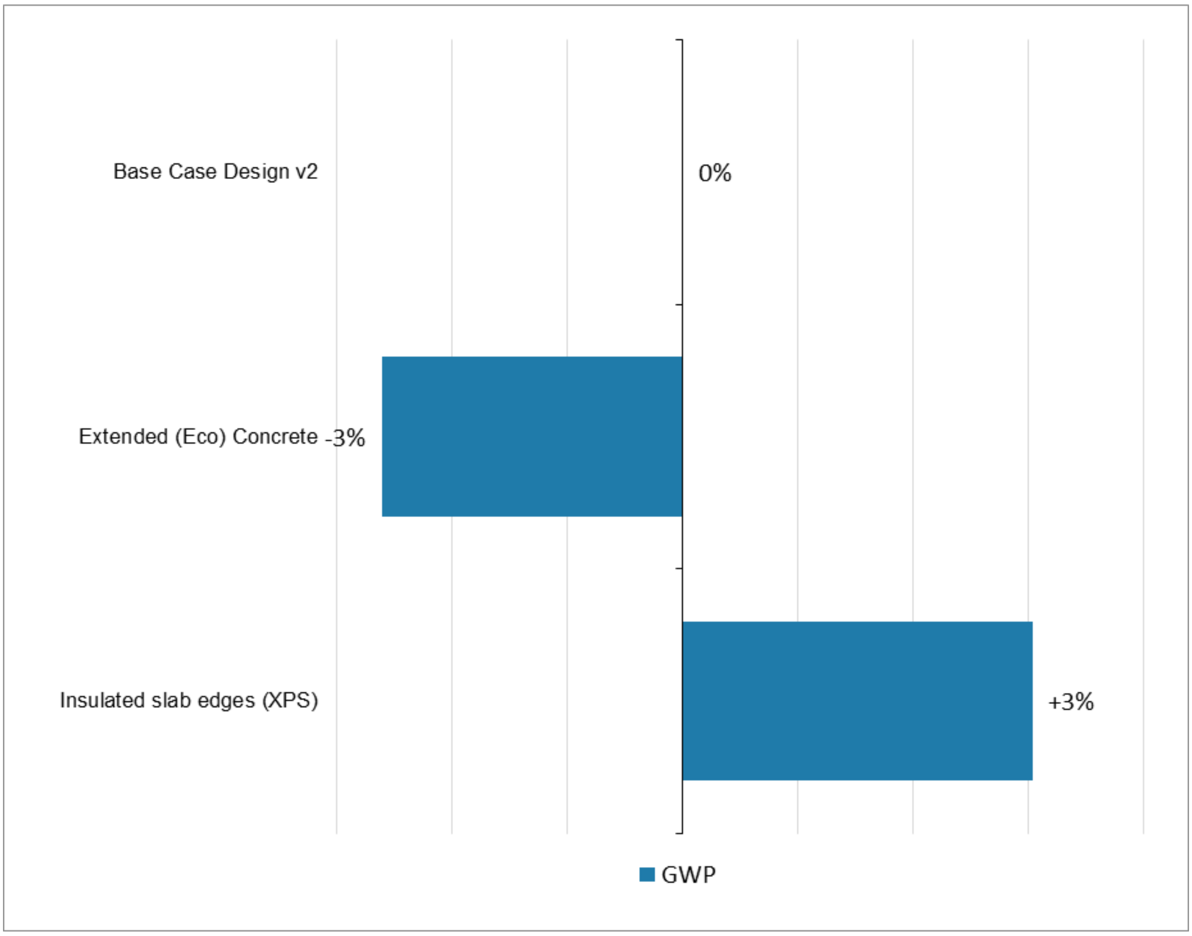

Figure 26 Relative Global warming potential results for Foundation Design Options compared to the Base Case Design

Table 40 Relative LCIA results for Foundation Design Options compared to the Base Case Design

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Extended (Eco) Concrete	-3%	+0%	+1%	+0%	+1%	+0%	+2%
Insulated slab edges (XPS)	+3%	0%	+0%	0%	+2%	0%	+3%

3.2.3 Additional scenarios

3.2.3.1 Rainwater tank scenarios

Two scenarios for the rainwater tanks are presented below:

- Reduction in water use from 122 to 100 L/person/day
- Increase tank life from 20 years to 40 years

As previously discussed in section 2.2.2.1, both of these scenarios include reductions in the amount of steel (and liner) used for tanks and replacement tanks. Reducing water use also leads to further reductions in electricity consumption for the pressure pump and reductions in emissions from the waste water treatment plant.

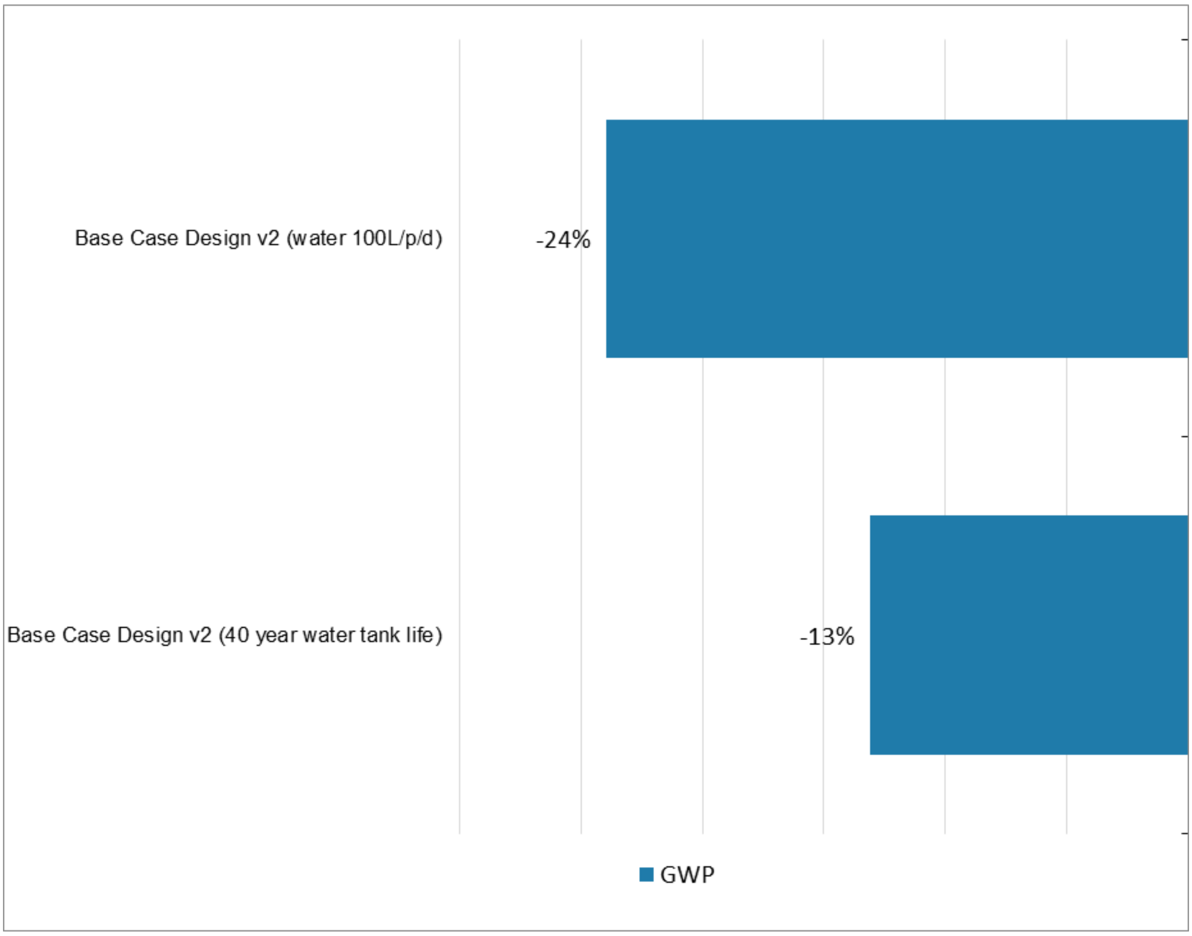

Figure 27 Relative Global warming potential results for rainwater scenarios compared to the Base Case Design

The detailed GWP results for the Base Case Design assumptions (122 L/person/day and 20-year tank life) rainwater scenarios are shown in Table 41.

Table 41 Global warming potential results for rainwater tank scenarios compared to the Base Case Design (Note that differences between the chart and the table are due to rounding).

Item	Base Case Design (122 L/p/d, 20-year tank life)	Water use 100 L/p/d		40-year tank life	
	GWP (kg CO_2e)	GWP (kg CO_2e)	Change	GWP (kg CO_2e)	Change
Rain water tank(s)	13,041	8,280	-37%	6,774	-93%
Pressure pump electricity	18,305	14,959	-18%	18,305	0%
Water treatment plant	18,338	14,985	-18%	18,338	0%
Total	49,684	38,224	-23%	43,417	-14%

Under the Base Case Design assumptions, the pressure pump electricity consumption and water treatment plant have similar GWP values (18,305 and 18,338 kg CO_2e) over the life of the dwelling. Decreasing the daily water use to 100 L/person/day reduces the GWP associated with the tanks by 37%, pressure pump electricity and water treatment plant both by 18%. The overall GWP reduction from reducing water use to 100 L/person/day was significant at 23%.

By increasing the tank life from 20 to 40 years reduces the GWP of the dwelling by 14%. The benefit of this is not just in the first tank but is the accumulated benefit over multiple tanks over the 80-year assumed life of the building.

The results of the rainwater tank scenarios highlight the importance of reducing water consumption as it not only conserves water, it also reduces emissions that cause global warming.

3.2.3.2 Use of average appliances

The LCA results for the Base Case Design assume that high-efficiency appliances[25] with MEPS Star ratings between 4 to 7 are used in the dwelling (see section 2.2.2.2). In a scenario where average appliances are used (with MEPS Star ratings between 1 and 2), the GWP is increased by +154% from -47,800 kg CO_2e to +26,000 kg CO_2e (Figure 28). The results for the other environmental impact categories are also higher for average appliances (Table 42). The use of average appliances in the building would therefore result in a building with net positive carbon emissions even when a 6.6 kWp solar PV system is included. The results of this scenario highlight the importance of the use of high-efficiency appliances in the dwelling to ensure a net carbon negative result.

[25] The appliances included in this list are televisions, clothes washing machine, computers, other entertainment and standby, dishwasher, miscellaneous electricity demand, clothes dryer. Refrigerators and freezers are not included.

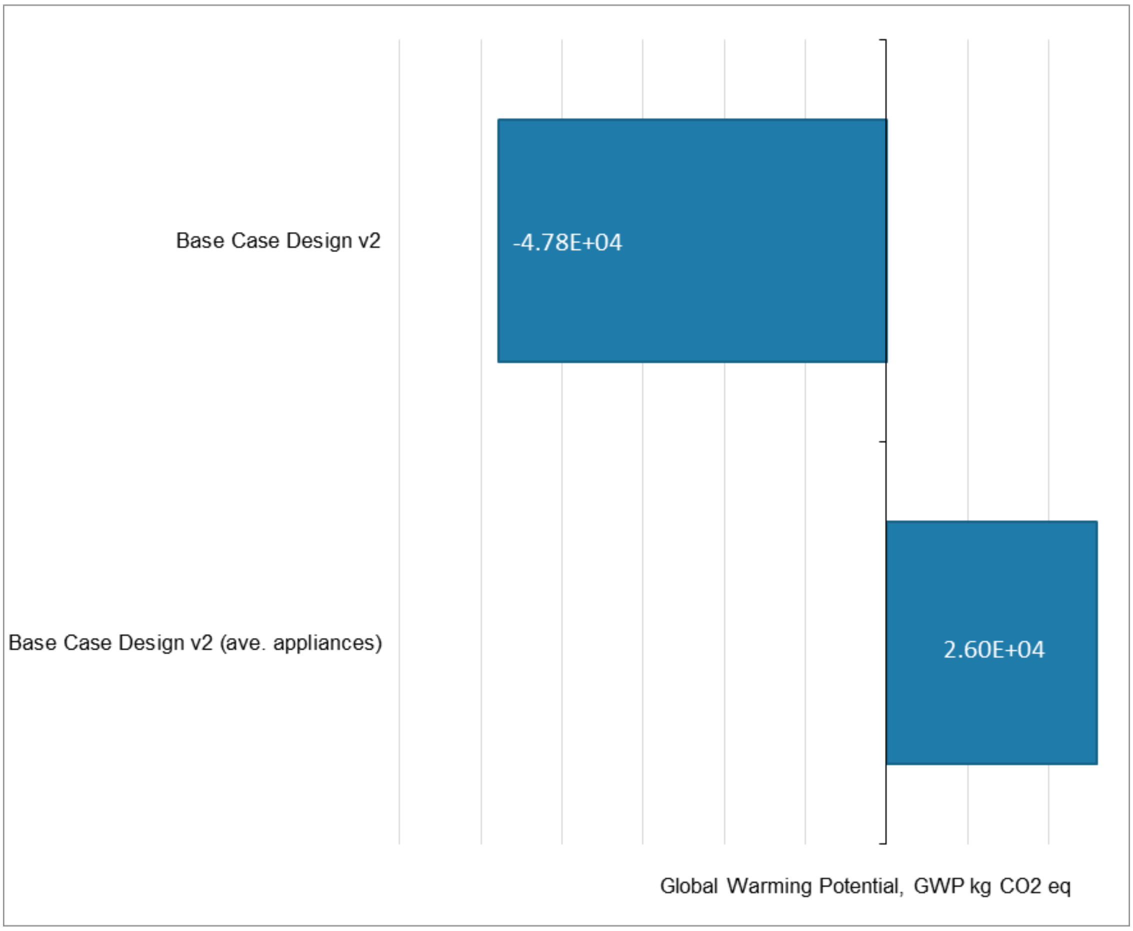

Figure 28 Global warming potential results for scenarios of average appliances

Table 42 Relative LCIA results for average appliances compared to the Base Case Design (high-efficiency appliances)

Design Option	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Base Case Design v2 (ave. appliances)	+154%	+1%	+16%	+14%	+6%	+1%	+93%

4 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the findings of the study:

4.1 MAXIMISE THE ELECTRICITY PRODUCTION OF SOLAR PV

- The study demonstrated that the use of solar PV is the current single most effective way to reduce the carbon footprint of the dwelling.
- Higher ADPE impacts from the use of solar PV can be further reduced by:
  - Ensuring that valuable substances are recycled at the end-of-life.
  - Selecting inverters that have a long product life.
  - Requesting life cycle information from equipment manufacturers to ensure that they are aware of – and actively taking steps to reduce – the environmental impacts of the products that they produce.
- It is recommended that the roof orientation of buildings and tree placement (to minimise shade) are planned to optimise the output of solar systems across the development[26].

4.2 RECOMMEND THE USE OF HIGH-EFFICIENCY APPLIANCES AND EQUIPMENT

- Hotspot analysis of the Base Case Design indicated that the use of high-efficiency air-conditioning, appliances and equipment (including refrigerators, freezers, televisions, dishwasher, washing machine, clothes dryer, computers, rainwater pumps and UV sterilisers) could significantly affect the environmental impact indicator results of the building.
- It is recommended that homeowners be informed of the importance of using high-efficiency air-conditioning systems, appliances and equipment.

4.3 RECOMMEND THE USE OF EXTERNAL WALL TYPES WITH HIGH INSULATION VALUES AND INTERNAL WALLS WITH HIGH THERMAL MASS

The conclusions from the assessment of wall Design Options are:

- The results for all wall Design Options were significant improvements over the Base Case Design with GWP reductions of between -98% to -141%[27].

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[26] The ideal arrangement of solar modules for the development may be different from simply facing due north at an angle equal to the latitude. To optimise production across the day a combination of east, north, and west facing modules may be required. Further investigation of building roof orientation may be required.

[27] When interpreting the results, it is important to keep in mind that the base case scenario - against which the different design options are compared - already includes a 6.6 kW solar PV system (as this is a requirement for all dwellings in the village). This means that percentage difference in results compared to the base case scenario are larger than they would be if the base case scenario was a typical dwelling that didn't use solar PV and instead consumed electricity from the grid.

- The wall Design Options with the lowest carbon footprints overall (including additional scenarios) were:
    - Strawbale infill with clay render and internal mud-brick walls (-187%[27] compared to the Base Case Design).
    - Timber frame with reverse mud-brick veneer and mud-brick internal walls (-178%[27] compared to the Base Case Design).
- Increasing the internal thermal mass of all Design Options through the use of clay brick (or even lightweight brick) lead to better thermal performance and lower greenhouse gas emissions over the life cycle of the building.
- The use of ERV units in SIPS buildings does result in a slightly higher carbon footprint (compared to a SIPs building without an ERV unit) due to electricity consumption. Due to the airtight nature of many of the wall types, ERV units may need to be considered to ensure adequate ventilation. Where used, ERVs should be controlled using automatic occupancy sensors (e.g. carbon dioxide sensors) to reduce electricity consumption as much as possible.

4.4 RECOMMEND THE USE OF TIMBER EXTERNAL CLADDING

- The use of fibre cement external cladding increased the GWP by 6% compared to a Timber frame wall with timber cladding; therefore, timber cladding should be used where possible to reduce the carbon footprint of the building further.

4.5 RECOMMEND THE USE OF DOUBLE-GLAZED WINDOWS WHERE SUITABLE

- The LCA results for windows were lowest for the double-glazed timber and uPVC windows.
- This study assumes that all windows in the dwelling are of the same type; however, conducting thermal modelling of each proposed dwelling will enable further cost and thermal performance optimisation of specific glazing combinations.

4.6 RECOMMEND WELL INSULATED CEILINGS (BUT AVOID THE USE OF WOOL INSULATION)

- The LCA results demonstrated the benefits of using high levels of ceiling insulation than the BCA minimum requirement.
- The GWP results for the wool insulation were significantly higher than other ceiling insulation types that were investigated. These results were cross-checked with several peer-reviewed studies which confirmed high GWP values for wool were due to the enteric methane emissions from the animal's digestive systems.

4.7 RECOMMEND THE USE OF TIMBER, MARMOLEUM, OR EARTH FLOORING

- The LCA results were lowest for local solid timber flooring, Marmoleum/linoleum or earth flooring.
- The results for polished concrete (grind and seal) were similar for tile floors.
- The results for earth flooring were similar whether the flooring was on top of the slab or a rock/sand base due to the additional concrete required for extra wall foundations.
- The wool carpet had higher GWP due to the enteric emissions from the sheep digestive systems.

4.8 RECOMMEND THE USE OF LOCAL SUPPLEMENTARY CEMENTITIOUS MATERIALS IN SLAB FOUNDATIONS

- The use of fly ash in the foundations lead to a slight reduction in the GWP of the building.
- The use of insulated slab edges increased the GWP over the life of the building so are not recommended for this building design.

4.9 RECOMMEND THE USE OF WATER SAVING INITIATIVES TO REDUCE THE CARBON FOOTPRINT OF THE DWELLING

- The LCA results demonstrated that by reducing the water consumption from 122 to 100 L/person/day could produce significant reductions in GWP (-24%). These reductions are achieved by reducing the electricity consumption of the water pump, reducing the size of the rainwater tanks required, and by reducing the GWP of the wastewater treatment plant.

4.10RECOMMENDATIONS FOR FURTHER RESEARCH

- The study highlights the importance of thermal modelling and LCA to select the most appropriate materials for the specific building design. It is recommended that further research is conducted for each design to optimise environmental performance over the entire life cycle.
- This LCA study was developed to enable valid comparison between design options and some design elements have been excluded (e.g. fixtures and fittings) as they are common to all designs, therefore, the inclusion/exclusion have no impact on the results. It is recommended to expand the scope of the study to include these elements into the building LCA models before making any claims of the carbon neutrality of the Cottage Lot design.
- Alternative wall construction methods including; mud/earth brick and light earth, could also be investigated.

- The additional building material templates that have been produced as part of this study could be added to the eToolLCD database to facilitate the development of a streamlined building LCA process that could be used to rapidly and cost-effectively assess the life cycle of each building design to suggest further improvement options.
- Life cycle assessment could be used to assess each aspect of the Witchcliffe Ecovillage to identify additional areas of improvement and to quantify the carbon footprint of the whole development.

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6 APPENDIX A – CRITICAL REVIEW STATEMENT AND REVIEW DETAILS

eTool PTY LTD
18 Howard Street, Perth WA, Australia
13/3/2019

RE: Review LCA Study of the Example Dwelling for Design Guidelines Development located at Witchcliffe, WA.

To Whom it May Concern

I have completed an independent review of the LCA work produced by Andrew D Moore from Life Cycle Logic. The study is of a very high standard with robust inventory analysis, very detailed options investigation and an extremely well documented report. The review has been conducted on the updated study initially reviewed by Fei Ngeow. For the purposes of transparency and audit trail the initial reviewer comments have also been included in this review statement.

Any departure or questions raised in this most recent review are relatively minor clarifications and observations and should neither detract from the overall quality of the study nor influence the results, recommendations or conclusions.

Regards,

Richard Haynes

eTool PTY LTD

eTool®

Review of Life Cycle Assessment

Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development

Date : 16/06/2020

LCA Study Author : Andrew D Moore

Peer Reviewers: Fei Ngeow and Richard Haynes

Version: 3

Overview

Andrew D Moore from Life Cycle Logic is conducting an LCA study for Witchcliffe Ecovillage- Passive Solar Cottage Lot, Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development located at Witchcliffe, WA. Fei Ngeow and Richard Haynes from eTool PTY LTD is conducting a review of this study.

The Review Process

This critical review has been carried out according to ISO 14040: 2006, clause 7.3.2 and ISO 14044: 2006. The study and has been reviewed against the requirements of EN 15978.

The review focussed on the following areas:

- Determine that the study adequately represents the environmental improvements given the background data and methodology used
- Ensure the study meets the requirements of ISO 14044
- Ensure the study meets the requirements of EN15978

The review timeline is outlined below:

Date of Exchange	Item	Author
16/07/2019	Requested Review of Initial “Base Design” study	Andrew D Moore
23/07/2019	Assigned for Review	Fei Ngeow
25/07/2019	Feedback Requested	Fei Ngeow
30/07/2019	Feedback Provided	Andrew D Moore
31/07/2019	Feedback Requested	Fei Ngeow
31/07/2019	Feedback Provided	Andrew D Moore
01/08/2019	Feedback Requested	Fei Ngeow
01/08/2019	Feedback Provided	Andrew D Moore
01/08/2019	Review of Initial “Base Design” study completed	Fei Ngeow
9/12/2019	Requested Review of Initial “Base Design V2” and design options study	Andrew D Moore
15/1/2020	Assigned for Review	Richard Haynes
13/3/2020	Feedback Requested	Richard Haynes
16/06/2020	Feedback Provided	Andrew D Moore
16/06/2020	Final Review Provided	Richard Haynes

The review findings along with the study author’s responses are documented in the following sections.

The Reviewers

Fei Ngeow

Fei Ngeow is a competent LCA practitioner, Coach and a Specialist user of eToolLCD. She has a Masters in Sustainability & Climate Policy and has been working at eTool since 2013.During her time at eTool, she has completed over 40 LCAs including:

- LCA of the Amer Sport Warehouse Centre at Braeside, Victoria. Conducted for Sustainable Development Consultants Pty Ltd. Primary motivation was for Green Star Certification. Completed in July 2019.
- LCA of a 2 story residential triplex building at White Gum Valley, Perth. Conducted for LandCorp. Primary motivation was to generate an as-designed footprint report. Completed June 2019.
- LCA of a 2 story residential dwelling at White Gum Valley, Perth. Conducted for LandCorp. Primary motivation was to generate an as-designed footprint report. Completed June 2019.
- LCA of the Key 7 Industrial Park Warehouse & Office Facility at Keysborough, Victoria. Conducted for Fraser Property. Primary motivation was for Green Star Certification. Completed in May 2019.

- LCA of Infrastructure and Public Domain at the Waterbank Development, Perth. Conducted for Lendlease. Primary motivation was for Green Star Certification. Completed in April 2016.
- LCA of 2x multi-storey residential projects at Hastings St and Beaufort St, Perth. Conducted for Psaros. Primary motivation was to quantify and improve greenhouse gas emissions over the life of the building. Completed in October and August 2014, respectively.
- LCA of a residential triplex project at Hope Street, White Gum Valley. Conducted for David Barr Architects. Primary motivation was to quantify and improve greenhouse gas emissions over the life of the building. Completed in August 2014.

This statement confirms Fei Ngeow's competency as an LCA practitioner.

Richard Haynes

Richard is a resource engineer with more than 20 years experience in project management business management, consulting and software design. He is a founding director of eTool and has over 50 LCAs of commercial, residential, material product and infrastructure projects and reviewed numerous studies for a range of organisations and projects. A small selection of these include:

- LCA of Thurrock Council Civic Offices (UK, 2019)

- LCA of Oasis Community Learning, Temple Quarter Secondary School (UK, 2019)
- LCA of Townhouses at Lot 4023 Ellesmere St, North Perth (Australia 2018)
- LCA of Montario Quarter Infrastructure and Public Domain (Australia 2018)
- LCA of Australian Catholic University Watson Campus, Veritas Building (Australia 2017)

In his career he has have also conducted energy audits, energy management consulting and GHG inventory reporting. Clients have included local governments, state governments, large utilities and numerous businesses.

This statement confirms Richard's competency as an LCA practitioner.

General Comments

The study is of a very high standard with robust inventory analysis, very detailed options investigation and an extremely well documented report. It is worthy of publication. The review has been conducted on the updated study initially reviewed by Fei Ngeow. For the purposes of transparency and audit trail the initial reviewer comments have also been included in this review statement.

The questions raised in this most recent review are relatively minor clarifications and observations and should not detract from the overall quality of the study. All dialogue between the reviewer and the study author has been provided for transparency.

Detailed Feedback

Temporal Relevancy		
Is the project start date correct?		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes. This study is being used to inform the WEV Design Guidelines	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - project start date is within 2 years of certification.	
If the project start date is not with 2 years of today, do templates reflect the processes employed at the time of the start date		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - project start date is within the next 2 years.	
The grid era (year if available) reflects the chosen start date		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes. The Village will be connected to the WA SWIS, however, have battery clusters and PV to minimise consumption from the grid.	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - grid era reflects start date.	
The LCI source is appropriate for the era of the design		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Passed on 24/07/2019 by Fei Ngeow : PASS - appropriate LCI source has been used for the era of the design.	Passed
Is the estimated service life applicable for the study? Are the attributes that influence design life considered and appropriately selected?		
Base case design	Comment on 16/07/2019 by Andrew D Moore : It is expected that the buildings will be around for 100 years +	Passed
	Questioned on 24/07/2019 by Fei Ngeow : According to our suburb calculator, Witchcliffe would have a suburb redevelopment potential of 'rural'. Please refer to this article to download our occupancy calculator and for more information about the built-in service life calculator: https://support.etoollcd.com/index.php/knowledgebase/service-life/	

eTool

	Comment on 25/07/2019 by Andrew D Moore : Updated. Yes, it is rural now but this design is part of a new subdivision so the area will be/has been rezoned to residential. Given that the village is restricting building types to those that will have a long service life I, therefore, made the development pressure low (80-year life) to be conservative. If you are happy with a 100-year life (Rural) then I'm happy with that!	
	Comment on 31/07/2019 by Fei Ngeow : Ultimately, the certifiers leave it to the study author's judgement as long as it's not unrealistic. We just provide some guidance. In the name of better environmental outcomes, we would also encourage more conservative assumptions to push for higher improvement goals. Since I believe these goals are more likely to be achieved in this project, I'm now thinking it would be beneficial to be more conservative. However that is your decision. Please confirm.	
	Comment on 31/07/2019 by Andrew D Moore : updated - ok 80 years it is for the base case design.	
	Passed on 01/08/2019 by Fei Ngeow : Update noted.	
Geographical Relevancy		
The correct project address has been entered (down to street level)		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Passed on 24/07/2019 by Fei Ngeow : PASS - correct project address has been entered.	Passed
The characteristics of the functions match the geographical location of the project (e.g., occupancy matches local statistical occupancy)		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes. The dwelling is designed to have 1-3 people but services (e.g. rainwater tank) are sized for 3 occupants.	Passed
	Questioned on 24/07/2019 by Fei Ngeow : The occupancy rate in our calculator is adjusted based on suburb density and other factors (so it won't be 3 people throughout the life cycle of the building). Please refer to this support post: https://support.etoollcd.com/index.php/knowledgebase/residential-occupancy/	
	Comment on 24/07/2019 by Fei Ngeow : Please update accordingly or clarify your assumptions.	
	Comment on 25/07/2019 by Andrew D Moore : Tricky. I have left it at 3 for now. As there is no reticulated water (rainwater tanks only!) the dwelling has to be designed for the intended number of people rather than the average number of people in the house... otherwise they will run out of water. The water use calculations have all been done on 3 people.	
	Comment on 31/07/2019 by Fei Ngeow : Hmm...yes I'm not against the logic of calculating water consumption based on 3 people however that number feeds into a few other templates in the design such as operational energy use (higher use = more conservative which isn't a bad thing) and in terms of	

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	functional unit it would mean the total impacts are shared among a higher number of 'occupants' which in reality is probably not going to be the case. I'm not sure how well these differences will balance each other out but again I'll leave it for you to decide on how you want to make that call. Please confirm.	
	Comment on 31/07/2019 by Andrew D Moore : Leaving it at 3 people. Having 3 people will be more conservative for both water and electricity use especially as the FU being used is Absolute (whole dwelling) rather than on pp basis.	
	Passed on 01/08/2019 by Fei Ngeow : Noted. Characteristics of the functions match the geographical location of the project.	
	Comment on 20/02/2020 by Richard Haynes: If the functional unit was changed to "provision of housing to an occupant" or comparisons made against the OECD benchmark the occupancy will need to be updated to match Australian Bureau of Statistics average occupancy per bedroom figures. I agree 3 occupants is conservative for reporting impacts "per dwelling" but if reporting per occupant it will under-estimate impacts (over-state performance) as higher occupants per dwelling mean less impacts per occupant (less material impacts and less base load energy/water per occupant).	
	Response by Andrew D Moore: OK. There are no plans to change the functional unit of the study. If in the future the functional unit is changed these points will be taken into consideration.	
	Comment on 16/6/2020 by Richard Haynes: Understood.	
The uploaded documents (Plans etc) match the project address		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - project address matches uploaded documents.	
The references in the largest contributing templates are relevant for the location of the project (e.g., not using a Building Code from Australia to define assumptions for a project in Europe)		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - references in the largest contributing templates are relevant for the location of the project.	
The correct structure address has been entered (down to lot or street number) and falls within the project address		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Passed on 24/07/2019 by Fei Ngeow : PASS - correct structure address has been entered.	Passed
The LCI source is appropriate for the location chosen (same country or continent)		
Witchcliffe Ecovillage Example Dwelling for	Passed on 24/07/2019 by Fei Ngeow : PASS - LCI source is appropriate for the location chosen.	Passed

Design Guidelines Development		
Precision		
The largest contributing template quantities have at least two significant figures entered		
Base case design	Passed on 24/07/2019 by Fei Ngeow : PASS - based on design documents provided, quantities that might be significant have been aggregated in templates appropriately.	Passed
The largest contributing EPD quantities have at least two significant figures entered		
Base case design	Comment on 16/07/2019 by Andrew D Moore : NA	Passed
	Passed on 24/07/2019 by Fei Ngeow : N/A - no EPDs used.	
The largest contributing elements (materials, operational, people and equipment) have at least two significant figures		
Base case design	Passed on 24/07/2019 by Fei Ngeow : PASS - largest contributing elements have at least 2 significant figures entered.	Passed
The values site characteristic values such as cold water inlet temperature are appropriate (match average ambient temp for location)		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Questioned on 24/07/2019 by Fei Ngeow : Water inlet temperature has been left at the default value. Please refer to this post for the appropriate water inlet temperature for different locations in Australia and update as appropriate: https://support.etoollcd.com/index.php/knowledgebase/water-inlet-temperature-australia/	Passed
	Comment on 01/08/2019 by Andrew D Moore : Set to 17.6 C (AS/NZS 4234:2008)	
	Comment on 01/08/2019 by Andrew D Moore : The new hot water system template doesn't use that but good to have in case I swap between other HWS templates.	
	Passed on 01/08/2019 by Fei Ngeow : Update noted.	
Completeness		
The target structural scope defined in the structure only deviates from the default scope where justified		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Questioned on 24/07/2019 by Fei Ngeow : Construction scope has not deviated from the default scope which is missing end-of-life demolition impacts. Please include 'Major Demolition Works' under 'Facilitating Works' in the scope to account align with EN15978 standards.	Passed
	Comment on 31/07/2019 by Andrew D Moore : Major Demolition Works added.	

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	Passed on 01/08/2019 by Fei Ngeow : Update noted. Target construction scope is in-line with EN15978 and adequate for the study.	
The target operational scope defined in the structure only deviates from the default scope where justified		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Passed on 24/07/2019 by Fei Ngeow : PASS - target operational scope defined in the structure is appropriate for the study.	Passed
The user entries for materials, people and equipment span the target structural scope defined in the structure		
Base case design	Passed on 24/07/2019 by Fei Ngeow : PASS - all entries are within scope	Passed
The user entries for energy and water span the target operational scope defined in the structure		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - all entries for energy and water are within scope.	
The useful functions of the building have been included		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - useful building function(s) have been included.	
The common area functions of the building have been included		
Base case design	Comment on 16/07/2019 by Andrew D Moore : na	Passed
	Passed on 24/07/2019 by Fei Ngeow : N/A - Common areas have been included within main building function and templates.	
The useful functions of the building contain templates / elements		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - useful building function(s) contain templates/elements.	
The common area functions of the building contain templates / elements		
Base case design	Comment on 16/07/2019 by Andrew D Moore : na	Passed
	Passed on 24/07/2019 by Fei Ngeow : N/A - no common area function as it has been included within the whole building function.	

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The life cycle modules included in scope are adequate for the goal of the study (excluded modules must be justified)		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Passed on 24/07/2019 by Fei Ngeow : PASS - all modules have been included in scope which are in line with EN15978 and adequate for the study.	Passed
Exclusion of Trades Staff Transport	Questioned on 23/2/2020 by Richard Haynes: The original study reviewed by Fei included emissions relating to small equipment and trades staff transport. There's some conjecture about this topic. EN15978 asks for quantifying transport of "Equipment" to and from the construction site and generally construction workers use some type of equipment on the job (even if it's not powered). So although the transport of the people should be excluded, the transport of the equipment is meant to be in. The other big factor is the consequence of different design decisions, if transport of trade staff to install / maintain the building component is excluded is it a fair comparison between a prefabricated / low maintenance solution vs alternatives? In summary, I think the exclusion of trade staff transport is in alignment with the way industry is generally interpreting the standard (eTool excluded) however that interpretation carries some risk of net negative design decisions.	Passed
	Response by Andrew D Moore: Agreed. The transport of equipment and trade staff was initially included; however, it was found that for many templates the underlying data was inconsistent which lead to potentially misleading results. The software has limited functionality to edit detailed transport parameters, so a pragmatic decision was made to exclude these impacts (in line with the common understanding of EN15978) and document accordingly.	
	Passed on 23/2/2020 by Richard Haynes: Understood and entirely acceptable. Thanks for clarifying.	
The Indicators included in scope are adequate for the goal of the study (excluded indicators must be justified)		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Passed on 24/07/2019 by Fei Ngeow : PASS - Main indicators included as default for the LCI Source used. No additional indicators included.	Passed
The structure contains a "Base" and "Improved" design for the purposes of improving performance		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Passed on 24/07/2019 by Fei Ngeow : PASS - structure contains a "Base" & "Improved" design for a comparative study.	Passed
Technological Relevancy		
The materials elements and templates entered reflect the actual technology employed in the design		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 25/07/2019 by Fei Ngeow : PASS - majority of the material elements/templates entered sufficiently represent the technology employed in the design based on the documentation provided.	

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The people and equipment elements and templates entered reflect the actual technology employed in the design		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Questioned on 24/07/2019 by Fei Ngeow : No end-of-life demolition impacts included. Please include to align with EN 15978 impact allocation methodology. You might want to look at the 'Ground Services - Standard (Residential)' template which also includes a few other nested templates besides demolition (i.e. site surveys & inspections, Site electrical works etc) which you may like to include in your study. Please read the template description for more details.	
	Comment on 29/07/2019 by Andrew D Moore : * Added Ground Services - Standard (Residential)	
	Passed on 31/07/2019 by Fei Ngeow : Update noted.	
The energy elements and templates entered reflect the actual technology employed in the design		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Questioned on 25/07/2019 by Fei Ngeow : I noticed that you've selected high efficiency applicances. Will the builder/developers be supplying the appliances? Basically, we're looking for some guarantee (builder supplied/building approval requirement etc) that high efficiency appliances will definitely be installed at least at the start of the building life.	
	Comment on 29/07/2019 by Andrew D Moore : * changed to "Appliances, Residential Average (AUS) Op&Em"	
	Passed on 31/07/2019 by Fei Ngeow : Update noted.	
V2 Designs	Questioned on 24/02/2020 by Richard Haynes: There is some discussion in the study regarding Abiotic Resource Depletion of Elements associated with the PV Systems. The Author has made some relevant updates to the inverter size. It is also likely that the panels themselves are lighter per kW capacity (the eToolLCD template library has recently been updated to reflect this). Not necessary to update the study but felt it was worth communicating the most recent findings on this topic. There is probably also likely a required update to the characterisation factors for Tantalum in the background data also (the large scale move from Tantalum to Polymer technology in the capacitor sector has likely reduced the strain on this resource).	Passed
	Response by Andrew D Moore: I agree that the potential environmental impact of solar PV is constantly improving so the actual results could be better than presented. A conservative assumption has been used.	
	Passed on 16/06/2020 by Richard Haynes: Understood.	
Reliance on NatHERs Thermal Simulation	Questioned on 23/2/2020 by Richard Haynes: The NatHERs and associated CSIRO's Chenath Calculation Engine are a great set of tools and standards. It is important though to recognise the key assumptions that dictate NatHERs results such as: • Occupancy: ○ For living spaces: thermal comfort is maintained from 7.00am to midnight	Passed

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	○ For sleeping spaces: thermal comfort is maintained from 4.00pm to 9.00am • Thermostat Set Points: ○ For sleeping spaces (including bedrooms and other spaces closely associated with bedrooms): a minimum heating thermostat setting of 18 degrees Celsius is used from 7.00am to 9.00am and from 4.00pm to midnight; and a heating setting of 15 degrees Celsius from midnight to 7.00am. ○ For living spaces (including kitchens and other spaces typically used during waking hours): a minimum heating thermostat setting of 20 degrees Celsius is applied. ○ The cooling methodology is based on the Effective Temperature method of calculating thermal comfort. The cooling thermostat setting varies according to the climate zone to account for the acclimatisation of local residents. • Infiltration: ○ Infiltration does take into account a range of factors including wind speed, openings, vents, cavities, types of windows/doors etc but it doesn't allow for very well sealed homes (e.g. Passive Haus standard). In some cases, particularly with highly sealed buildings NatHERS won't provide accurate results. It is my opinion that this would not necessarily change the conclusions of the report but probably worthwhile being clear about the inputs.	
	Response by Andrew D Moore: Text and reference added to section 3.1.1.1, page 50.	
	Passed by Richard Haynes: Noted, thanks.	
Energy Recovery Ventilator Discussion	Questioned on 23/2/2020 by Richard Haynes: I think this is worth a separate point / recommendation specifically on this topic. Energy Recovery Ventilators typically draw 500W and running one for 24 hours a day would use more energy than an efficient air-conditioner in a code compliant (relatively poorly sealed) Australian home. If energy recovery ventilators are to be used, they *must* be automatically controlled for occupancy and/or CO2 to prevent large unnecessary energy use.	Passed
	Response by Andrew D Moore: Text added to 3.2.1.5 SIPS pg 59 to further emphasise that ERVs should be use with sensors to prevent high energy consumption. Other sections already include text stating that sensors should be used with ERV units.	
	Passed on 16/06/2020 by Richard Haynes: Awesome, thanks.	
Window Analysis	Questioned on 13/3/2020 by Richard Haynes: Why is low E glass higher impact than standard glass with the same frame?	Passed
	Response by Andrew D Moore: This question was raised with the NatHERS modeller who stated that there was limited resolution to explain results from the modelling software. Inputs and results were triple checked. The logical explanation is that if low-E glass is used on the entire building, including the northern side, it prevents passive solar gain and therefore increases energy consumption for heating.	
	Passed on 16/06/2020 by Richard Haynes: Understood, that makes sense.	
The water elements and templates entered reflect the actual technology employed in the design		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed

	Questioned on 24/07/2019 by Fei Ngeow : Will the dwelling be connected to mains water at all?	
	Comment on 24/07/2019 by Fei Ngeow : I would like to see some evidence that the capacity of the rainwater tanks will be sufficient to supply all the water needs of the occupants throughout the predicted service life of the dwelling.	
	Comment on 29/07/2019 by Andrew D Moore : * modelling using the average rainfall for Witchcliffe over the last 19 years (2000-2019) shows that a 88kL rainwater tank will provide 100% of the 366L/day. Key assumptions and results: -Household water consumption (L/day):366 -Roof area (m2):191 -Tank volume (kL): 88 -Average Rainfall days (days): 171 -Average days rainfall flowed to tank (days): 171 -Total volume hits roof area (L): 186,040 -Total volume to tank (L): 155,565 -Tank overflow (L): 30,324 -Rainwater used (L): 133,590 -Days tank is at minimum level (days): 0 -Days rain water used (days): 365 -Days rain water used: 100% -Rain water share of total water use: 100% -Maximum tank level reached (kL): 88 Other base assumptions are: -Minimum tank level: 5% -First flush volume: 15L -Efficiency of rainwater collection system: 85% -Absorbance of roofing: 0mm per rainfall event (metal sheet)	
	Passed on 31/07/2019 by Fei Ngeow : All good. I've also cross checked with tankulator and the figures match up.	
The default grids selected for the project are representative of the technology used in the actual grids on the project site.		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Questioned on 24/07/2019 by Fei Ngeow : For 'Default electricity grid (EXPORT)', if applicable please select the appropriate feed-in grid. In this case it would be 'Feed In: AU WA SWIS '. Please update or clarify.	Passed
	Comment on 01/08/2019 by Andrew D Moore : Updated.	
	Comment on 01/08/2019 by Andrew D Moore : Is there a way to set the Default Water Supply Grid to None so that the model uses the rainwater instead of scheme water?	
	Passed on 01/08/2019 by Fei Ngeow : Update noted. I don't think there is much point because the consumption of rainwater (with tank & water pumping/filtration impacts accounted for separately) doesn't actually generate any GWP? So there wouldn't really be a need to add operational rainwater use figures into the design.	
Consistency		
Both operational water supply and treatment have been included		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes. Water treatment selected is average as the water treatment will be onsite and follow Health Dept requirements (e.g. no innovation is possible to reduce emissions or energy consumption)	Passed
	Comment on 24/07/2019 by Fei Ngeow : Only water treatment have been included. Pending clarification on operational water supply.	
	Passed on 31/07/2019 by Fei Ngeow : N/A - no mains water supply selected as the dwelling is not plumbed into mains water.	
Communication of the System Boundary is appropriate and the		

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Separation of B6 with Plug Loads	Questioned on 28/2/2020 by Richard Haynes: EN15978 requires that non-integrated equipment energy be separately reported. eToolLCD categorises this as "Module B6+". This departure from the standard does not affect the results of the study but could cause confusion if results were compared to other studies where only integrated energy is included.	Passed
	Response by Andrew D Moore: Agreed. It was considered important to include the non-integrated equipment/appliances to provide context over the life of the building.	
	Passed on 16/06/2020 by Richard Haynes: I think it's excellent that it's accounted for (personally) and support that approach. Thanks for the clarification.	
Where energy generation is employed and there is an expectation the system will export power, the exported power is allocated to module D		
Base case design	Comment on 16/07/2019 by Andrew D Moore : No. Currently in "Energy Generation Utilised B6"	Passed
	Questioned on 24/07/2019 by Fei Ngeow : Please confirm if all energy generated will be used on-site. If not, part of that energy generated will need to be split and allocated to module D.	
	Comment on 24/07/2019 by Fei Ngeow : Please refer to this post: https://support.etoollcd.com/index.php/knowledgebase/model-operational-energy-en15978/	
	Comment on 29/07/2019 by Andrew D Moore : PV split 71% consumed (B6) and 29% export (D1) based on the results in the Operational Energy page that shows how much electricity is consumed and how much is produced by the PV. Updated in both the Template and the template then reimported to the Base Case.	
	Comment on 29/07/2019 by Andrew D Moore : Hmm. That didn't seem to work. As there will be batteries, very little should come from the grid. I am getting the figures from the consultants but for now set to 5% grid.	
	Comment on 29/07/2019 by Andrew D Moore : No. Now I'm confused. Read the post and watched the video and still not clear. I may be confusing issues. Help!	
	Comment on 29/07/2019 by Andrew D Moore : Fixed. Seemed to be that if the formula in the video/blog example was used then the scaling (1kWp to 5.5 kWp) stopped working (e.g. only gave a 1kWp system when it was set to 5.5 kWp).	
	Passed on 31/07/2019 by Fei Ngeow : Update noted. All looks good.	
Where energy generation is employed and there is an expectation the system will export power, the exported power goes to an appropriate "Feed in" grid (if available)		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Questioned on 24/07/2019 by Fei Ngeow : Please confirm if any energy generated will be exported to the grid. If none, please ensure that all the energy generated is assigned to the default (import) grid to simulate the offset from the energy used from the grid. Any energy generated that will be exported to the grid will need to be separated from the total energy generated and assigned to the default feed-in (export) grid.	

	Comment on 24/07/2019 by Fei Ngeow : Please refer to this post: https://support.etoollcd.com/index.php/knowledgebase/model-operational-energy-en15978/	
	Comment on 29/07/2019 by Andrew D Moore : Done in Data Quality Check above (I think).	
	Passed on 31/07/2019 by Fei Ngeow : Update noted. All good.	
The characteristics of each function have been correctly entered		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - characteristics of each function have been correctly entered.	
The floor areas of the functions match the design documentation		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Questioned on 24/07/2019 by Fei Ngeow : I'm not sure why your unenclosed covered area is 248m2 which is larger than the FECA. I would say the UCA only includes the solar pergola, porch, car porch, bins & drying area (approx 82m2). Please clarify.	
	Comment on 29/07/2019 by Andrew D Moore : * Corrected Figures have been revised.	
	Passed on 31/07/2019 by Fei Ngeow : Update noted.	
An appropriate functional unit and time scale has been chosen		
Base case design	Questioned on 24/07/2019 by Fei Ngeow : None specified. A functional unit of kgCO2e/Occupant/year is recommended for predominantly residential projects.	Passed
	Comment on 29/07/2019 by Andrew D Moore : We are happy to leave the FU as "Absolute" i.e. the whole building and the time frame as "no time scale" i.e. the life of the building. These are appropriate for the study as we aren't comparing against other designs, only options within the same design.	
	Passed on 31/07/2019 by Fei Ngeow : Noted.	
The functional unit and time scale match the benchmark selected		
Base case design	Passed on 24/07/2019 by Fei Ngeow : N/A - design being assessed is the benchmark.	Passed
An appropriate benchmark has been selected to compare against each primary function (Usable spaces)		
Base case design	Passed on 24/07/2019 by Fei Ngeow : N/A - design being assessed is the benchmark.	Passed

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The structural scope of the benchmark matches that of the project		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Passed on 24/07/2019 by Fei Ngeow : PASS - construction scope matches as both the Base/Reference and Improved/Proposed Design are within the same project.	Passed
The operational scope of the benchmark matches that of the project		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Passed on 24/07/2019 by Fei Ngeow : PASS - operational scope matches as both the Base/Reference and Improved/Proposed Design are within the same project.	Passed
Where a benchmark is selected from another project, the life cycle modules included in scope are identical		
Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Questioned on 24/07/2019 by Fei Ngeow : None selected. Please clarify if a benchmark will be selected from another project.	Passed
	Comment on 01/08/2019 by Andrew D Moore : This base case will be the benchmark so no other benchmark selected.	
	Passed on 01/08/2019 by Fei Ngeow : Noted. Benchmark is from within the same project.	
Where a benchmark is selected from another structure, the structural and operational scope of the structures is identical (preferably the default scope)		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Questioned on 24/07/2019 by Fei Ngeow : Please clarify if a benchmark will be selected from another project.	Passed
	Comment on 31/07/2019 by Andrew D Moore : This Base Case Design will be the Benchmark against which alternative design elements will be compared.	
	Passed on 01/08/2019 by Fei Ngeow : Noted. No external benchmark used. Base/reference design is project benchmark.	
The Structure Type (building or infrastructure) has been appropriately chosen		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Passed on 24/07/2019 by Fei Ngeow : PASS - Structure has been appropriately chosen.	Passed
Reproducibility		
The services of the functions match the design documentation		
Base case design	Passed on 24/07/2019 by Fei Ngeow : PASS - services of the functions match the design documentation	Passed
Design documentation includes plans and elevations (or 3D model)		

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Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - plans and elevations included in documentation	
Design documentation includes structural drawings		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - structural drawings included in documentation	
Design documentation includes a services specification		
Base case design	Comment on 16/07/2019 by Andrew D Moore : No	Passed
	Passed on 24/07/2019 by Fei Ngeow : N/A - no services specifications have been made at this stage of the project. BAU services and assumptions have been selected for the purpose of this assessment.	
Where possible validated and global templates have been used		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes. Some customisation done.	Passed
	Questioned on 24/07/2019 by Fei Ngeow : Can you please point out which templates have been customised?	
	Comment on 25/07/2019 by Andrew D Moore : What's the best way to do this? Can you see much from your end as to which templates are validated/global and which ones I've modified/customised?	
	Comment on 29/07/2019 by Andrew D Moore : See xlsx change table provided via email.	
	Passed on 31/07/2019 by Fei Ngeow : Adjustments made to existing templates are sound and new templates have accounted for most of the impacts relating to the item it's representing with good references although there is a tendency to be a bit lacking on assembly impacts (off-site manufacturing).	
Design documentation includes energy simulation report for HVAC		
Base case design	Comment on 16/07/2019 by Andrew D Moore : Yes	Passed
	Passed on 24/07/2019 by Fei Ngeow : PASS - HVAC energy simulation report included in documentation	
Has the Assessor provided sufficient design documentation to allow a useful Certification?		
Base case design	Passed on 24/07/2019 by Fei Ngeow : PASS - sufficient design documentation provided.	Passed
The project description adequately describes the site and functional brief of the entire project		

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Witchcliffe Ecovillage Example Dwelling for Design Guidelines Development	Questioned on 24/07/2019 by Fei Ngeow : None provided. This info will be automatically transferred to the LCA report to increase report quality and transparency. Please refer to this page for more information on what kind of information to provide: https://support.etoollcd.com/index.php/knowledgebase/project-structure-description/	Passed
	Comment on 01/08/2019 by Andrew D Moore : Added.	
	Passed on 01/08/2019 by Fei Ngeow : Update noted.	
The structure description adequately describes the functional brief of the structure along with design goals.		
Witchcliffe Ecovillage-Passive Solar Cottage Lot	Questioned on 24/07/2019 by Fei Ngeow : More detail required in the description of the structure as this field will populate the final automated LCA report. Please refer to this article for guidance on what information to provide: https://support.etoollcd.com/index.php/knowledgebase/project-structure-description/	Passed
	Comment on 31/07/2019 by Andrew D Moore : Project and structure descriptions added.	
	Passed on 01/08/2019 by Fei Ngeow : Update noted. Structure information has been adequately described including the functional brief and design goals.	
Has a draft Life Cycle Assessment report been provided to capture the progress at the time the review was requested?		
Base case design	Questioned on 24/07/2019 by Fei Ngeow : No draft LCA report saved to the design. Please generate draft LCA report to reflect current impacts of the design. The report acts as a snapshot of the design at the point of submission for certification and is a backup should any issues arise in the future.	Passed
	Comment on 29/07/2019 by Andrew D Moore : Draft LCA report should be there now that includes recent changes (which should be fine for this project).	
	Passed on 31/07/2019 by Fei Ngeow : Update noted.	
Other Reproducibility Comments		
LCA Report - Page 78 Figure 15 GWP hotspots in the Base Case Design	Questioned on 24/02/2020 by Richard Haynes : I think these are the template names and they signify that the figures include embodied emissions in some instances but I'm guessing the graph is just operational?	Passed
	Response by Andrew D Moore: The graph category labels are based on the template names but they have been edited for presentation. These categories include both operational and embodied impacts, however, they assume that the electricity is all provided by the grid to demonstrate the benefit that efficient appliances can have even when solar PV is used (assuming exported PV electricity offsets electricity grid mix).	
	Passed on 16/06/2020 by Richard Haynes: Noted, thanks.	
Other Comments and Questions		
LCA Report		

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LCA Report - Page 5	Questioned on 20/2/2020 by Richard Haynes: Review is being conducted by Fei Ngeow and Richard Haynes.	Passed
	Response by Andrew D Moore: Text will be updated to reflect this.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	
Results and Interpretation - Design Options - Wall Types - Page 7	Questioned on 20/2/2020 by Richard Haynes: Commentary says straw bale the lowest impact but the chart says reverse brick veneer?	Passed
	Response by Andrew D Moore: As stated in the text, the lowest impact was the "Strawbale infill with clay render and internal mud-brick walls". As indicated, the figure only shows the default assumptions (e.g. base cases) rather all of the permutations investigated.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	
General Comment	Questioned on 20/2/2020 by Richard Haynes: The savings of different strategies are expressed in percentages against a base design with very low impacts due to the inclusion of a large solar PV system. There's significant scope for misinterpretation of this in the public domain. For example, "Timber double glazed windows reduce Life Cycle GWP impacts by 33%". If in fact you quoted the percentage reduction in a building without the large PV system it would be a 2.7% improvement. This also introduces some significant risk if the study was to be duplicated (if the Solar PV Base Design happened to be a very near zero figure all changes would represent +/- 1000s of percent. I'm not certain how or if this needs to be changed but wanted to raise the risk. Some suggested strategies may be: • Quote the savings against a non-PV baseline • Quote the savings against an average PV installed size in Australia baseline • Don't quote the savings in percentage terms (I think this makes it harder to read the report though)	Passed
	Response by Andrew D Moore: Yes, this was considered and discussed throughout the project. The logic, as outlined in the report, is that all of the dwellings will have (at least) a 6.6 kW PV system as this is part of the land package – building without PV is not an option. This does create the potential for misinterpretation which we could help to address by adding a paragraph in a separate box (in exec summary, results, and conclusion sections) to describe how to interpret the results. — **When interpreting the results, it is important to keep in mind that the base case scenario (against which the different design options are compared) already includes a 6.6 kW solar PV system. This means that:** • **Results are negative (e.g. the carbon footprint of the base case design is -47,800 kg CO_2e over the study period). The design options with the lowest values have lower impacts for each impact category.** • **Percentage difference are larger than they would be if the base case scenario didn't use solar PV and instead consumed electricity from the grid.** **The base case scenario includes solar PV as this is a requirement for all dwellings in the village.**	
	Passed on 16/06/2020 by Richard Haynes: That's smart, thanks.	

Comparative Assertions and Review Type	Questioned on 23/2/2020 by Richard Haynes: It's the reviewers opinion that the study is definitely making some comparative assertions (e.g. wall types) and hence the release of the study to the general public would breach ISO14044 without a panel review process. Notwithstanding that, the risk associated with this departure from the standard is very low due to: • The comparisons are investigations of design options conducted to inform design guidelines rather than intended to make direct comparisons of one building product to another. • The Commissioner, Author and Reviewers of the study have no vested interest in particular strategies being compared. • The assumptions and LCI associated with each design options are well documented and hence may be referred to and scrutinised and questioned by the audience • The comparisons have not highlighted instances where design options are so poor that they need to be excluded from the design guidelines. That is, the results of the comparisons are relatively modest in nature with few "stand out" very high performing or very low performing options.	Passed
	Response by Andrew D Moore: I agree that the guidance in ISO 14044 regarding the need for a panel review before making comparative assertions are not clear. This study does not claim "the environmental superiority" of one product or system over another which I see is the key requirement to trigger a panel review. In addition, the study clearly states that the findings are only relevant for the scope of the Witchcliffe Ecovillage.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	
Refrigerator-freezers Page 79	Questioned on 23/2/2020 by Richard Haynes: Whilst the recommendation to consider high-efficiency refrigerators and freezers is valid within the system boundary of the study it does carry some significant risk. The embodied impacts of the food stored in the refrigerator during its lifespan are likely an order of magnitude or more greater than the operational impacts of the refrigerators, so if a high efficiency refrigerator is unable to keep food in an edible state for as long as a lower efficiency fridge it will be a net negative outcome. In that sense, I think the key decision point on fridge selection. Choice Magazine actually rates fridges on both energy efficiency and "keeping food fresher longer" which takes into account Temperature stability, Temperature evenness and Response to outside temperature (not sure this is a perfect measure but it's a start). Designers can also include "well ventilated fridge space" and "minimise fridge space" strategies to influence refrigeration energy independently of the occupants refrigerator choice.	Passed
	Response by Andrew D Moore: Although interesting to consider these issues in future research they are considered to be outside of the scope of the current study.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	
Floor Coverings	Questioned on 23/2/2020 by Richard Haynes: Is there a reason that straight grind and polish concrete floors were omitted (e.g. traditional terrazzo floor)	Passed
	Response by Andrew D Moore: There are many different concrete floor finish types that were investigated as background to the study. The finish type included in the study was documented (including statement on page 92). Straight grind and polish concrete floor finishes require more mechanical grinding plus the use of several coats of chemical concrete hardeners (not available in the software database) to achieve the final result.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	

Water Use	Questioned on 4/3/2020 by Richard Haynes: The study would benefit significantly with quantification of efficient water fixtures and fittings. A 20% reduction in water use to 100L/person/day should be able to be comfortably surpassed with a combination of: • Efficient toilets • Efficient showers • Efficient taps • Minimisation of lawn areas, native plantings and/or sub-surface irrigation	Passed
	Response by Andrew D Moore: Agreed, however, further investigation is outside the scope of the current study. The base assumptions for water use and tank sizes (as documented in the report) were calculated and provided by the Witchcliffe Ecovillage. The importance of reducing water consumption as much as possible was investigated using scenario analysis (see section 3.2.2.1). Findings of the benefits were clearly documented.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	
Section 5.2 Recommended High Efficiency Appliances	Questioned on 4/3/2020 by Richard Haynes: there's a tendency for builders to interpret appliances as "dishwasher, oven, stove and range" as these are the only items they generally install. It appeared in the body of that plug loads and the efficiency of this equipment (particularly TVs) was a really high driver of the building's energy requirements (up there with refrigeration and air conditioning). Should that be included in the recommendation description?	Passed
	Response by Andrew D Moore: Agreed. The text for recommendations relating to high efficiency appliance will be revised to ensure that it clearly states which appliances are included in the recommendation.	
	Passed on 16/06/2020 by Richard Haynes: Noted.	
Section 5.10	Questioned on 13/3/2020 by Richard Haynes: Relating to other comments in the review, it's recommended the following are added (should the body of the study not be updated to address these items): • Specific analysis of grind and polish (traditional terrazzo) floor finish • Analysis of efficient water fixtures and fittings • Analysis of water efficient landscaping options • Consideration of the impacts of non-controlled Energy Recovery Ventilators	Passed
	Response by Andrew D Moore: Each of the listed items have been separately addressed in relevant sections of the reviewer dialogue table.	
	Passed on 16/06/2020 by Richard Haynes: Noted, thanks.	

7 APPENDIX B - DETAILED LCI TABLES

Detailed life cycle inventory of materials for the Base Case Design (v2) are presented below (Table 43).

For the detailed life cycle inventory tables of other design options please refer to the individual PDF files:

- 2020.06.15 Design Life Cycle Inventory v2.2 Strawbale infill (lime render).pdf
- 2019.10.11 Design Life Cycle Inventory v2 Timber frame reverse brick veneer.pdf
- 2019.10.11 Design Life Cycle Inventory v2 Timber frame.pdf
- 2020.06.15 Design Life Cycle Inventory v2.2 Hempcrete.pdf
- 2019.10.11 Design Life Cycle Inventory Strawbale infill v2 (clay render and internal mud brick walls).pdf
- 2019.10.11 Design Life Cycle Inventory v2 Base case design.pdf
- 2019.10.11 Design Life Cycle Inventory v2 SIPS (+ERV).pdf
- 2019.10.11 Design Life Cycle Inventory v2 Steel Frame.pdf

Table 43 Detailed Life Cycle Inventory of Materials for the Base Case Design

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Electricity mains supply	Site Power and Electrical Connection - Residential	Electricity Meter	Finished Products | Electrical Goods | Electrical Equipment | Industry Average (# unit equals $ Spent)	0	15	# (Default)	5	0.5	15	0	Electric motor Landfill
Electricity mains supply	Site Power and Electrical Connection - Residential	Switches	Finished Products | Electrical Goods | Inverter | Industry Average	0	0.5	kg	15	0.5	27	0	inverters Landfill
Electricity mains supply	Site Power and Electrical Connection - Residential	Copper wire 6mm	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	25	Count	7.5	0.5	30	48	Copper Landfill
Electricity mains supply	Site Power and Electrical Connection - Residential	Conduit 20mm diam	Plastics | Polyvinyl Chloride (PVC) | Unspecified | Industry Average	5	25	Count	20	0.5	30	20	Plastics Landfill
Electricity mains supply	Site Power and Electrical Connection - Residential	wire casing 3mm diam	Rubber | Synthetic | Industry Average	0	25	Count	10	0.5	30	0	Plastics Landfill
Electricity mains supply	Site Power and Electrical Connection - Residential	Meter box	Steel | General | Unspecified | Industry Average	40	2	Count	5	0.5	29	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Seeding and turfing	External timber deck (Alfresco) (External timber deck (Alfresco))	Weed control mat	Plastics | Polypropylene | Injection Moulding | Industry Average	0	2.8	kg	20	0.5	30	0	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Aluminium | General | Industry Average	35	0.39	kg	1	0.5	9	57.33	Aluminium Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Asphalt and Bitumen | Asphalt Unspecified | Industry Average	0	9.5	kg	10	0.5	9	0	Inert Waste Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	0.92	kg	7.5	0.5	9	48	Copper Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Metals (excluding steel and Aluminium) | Zinc | Industry Average	0	0.02	kg	7.5	0.5	9	0	Non-ferrous metals Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | ABS | Industry Average	5	0.8	kg	20	0.5	9	20	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | General | Unspecified | Industry Average	0	1.16	kg	20	0.5	9	0	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	5	0.02	kg	20	0.5	9	20	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | Polypropylene | Injection Moulding | Industry Average	0	8.81	kg	20	0.5	9	0	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | Polystyrene | Expanded Polystyrene | Industry Average	0	1	kg	20	0.5	9	0	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | Polystyrene | Expanded Polystyrene | Industry Average	0	1.018	kg	20	0.5	9	0	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Plastics | Polyvinyl Chloride (PVC) | PVC Injection Moulding | Industry Average	5	0.66	kg	20	0.5	9	20	Plastics Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Steel | General | Unspecified | Industry Average	40	15.4	kg	5	0.5	9	80	Steel products Landfill
Domestic kitchen fittings and equipment	Dishwasher Em	Dishwasher	Steel | Stainless | Unspecified | Industry Average	40	7.42	kg	5	0.5	9	80	Steel products Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Aluminium | General | Industry Average	35	4.22	kg	1	0.5	10	57.33	Aluminium Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Fibreglass | Unspecified | Industry Average	0	0.16	kg	15	0.5	10	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerant R134	Gases | Refrigerants | R134 | Industry Average	0	0.3	kg	2	0.5	10	0	Refrigerant Gas HFC - 134a Loss
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Glass | Flat Glass | Industry Average	0	5.74	kg	5	0.5	10	0	Glass Land Fill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Metals (excluding steel and Aluminium) | Brass | Industry Average	29	0.34	kg	7.5	0.5	10	48	Non-ferrous metals Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	5.4	kg	7.5	0.5	10	48	Copper Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Metals (excluding steel and Aluminium) | Iron | Industry Average	40	9.12	kg	7.5	0.5	10	71.75	Steel products Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Plastics | ABS | Industry Average	5	10.14	kg	20	0.5	10	20	Plastics Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Plastics | General | Unspecified | Industry Average	0	10.14	kg	20	0.5	10	0	Plastics Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Plastics | Polypropylene | Injection Moulding | Industry Average	0	1.02	kg	20	0.5	10	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Plastics | Polystyrene | Expanded Polystyrene | Industry Average	0	12.52	kg	20	0.5	10	0	Plastics Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Plastics | Polyurethane | Unspecified | Industry Average	0	11.14	kg	20	0.5	10	0	Plastics Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Plastics | Polyvinyl Chloride (PVC) | PVC Injection Moulding | Industry Average	5	2.02	kg	20	0.5	10	20	Plastics Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Rubber | Synthetic | Industry Average	0	0.34	kg	10	0.5	10	0	Plastics Landfill
Domestic kitchen fittings and equipment	Refrigeration, Residential Detailed (AUS) Em	Refrigerator unit	Steel | General | Unspecified | Industry Average	40	95.1	kg	5	0.5	10	80	Steel products Landfill
Fittings, furnishings and equipment	Clothes washer Em	Aluminium	Aluminium | General | Industry Average	35	2.7	kg	1	0.5	10	57.33	Aluminium Landfill
Fittings, furnishings and equipment	Clothes washer Em	Aluminium	Aluminium | General | Industry Average	35	2.7	kg	1	0.5	10	57.33	Aluminium Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	1.2	kg	7.5	0.5	10	48	Copper Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	1.2	kg	7.5	0.5	10	48	Copper Landfill
Fittings, furnishings and equipment	Clothes washer Em	Clothes washer	Metals (excluding steel and Aluminium) | Iron | Industry Average	40	0.4	kg	7.5	0.5	10	71.75	Steel products Landfill
Fittings, furnishings and equipment	Clothes washer Em	Clothes washer	Metals (excluding steel and Aluminium) | Iron | Industry Average	40	0.4	kg	7.5	0.5	10	71.75	Steel products Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Plastics | General | Unspecified | Industry Average	0	0.8	kg	20	0.5	10	0	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Plastics | General | Unspecified | Industry Average	0	0.8	kg	20	0.5	10	0	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Plastics | Polypropylene | Injection Moulding | Industry Average	0	9.1	kg	20	0.5	10	0	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Plastics | Polypropylene | Injection Moulding | Industry Average	0	9.1	kg	20	0.5	10	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Plastics | Polyvinyl Chloride (PVC) | Unspecified | Industry Average	5	0.5	kg	20	0.5	10	20	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Plastics | Polyvinyl Chloride (PVC) | Unspecified | Industry Average	5	0.5	kg	20	0.5	10	20	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Rubber | Synthetic | Industry Average	0	1.1	kg	10	0.5	10	0	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Washing Machine	Rubber | Synthetic | Industry Average	0	1.1	kg	10	0.5	10	0	Plastics Landfill
Fittings, furnishings and equipment	Clothes washer Em	Clothes washer	Steel | General | Unspecified | Industry Average	40	43	kg	5	0.5	10	80	Steel products Landfill
Fittings, furnishings and equipment	Clothes washer Em	Clothes washer	Steel | General | Unspecified | Industry Average	40	43	kg	5	0.5	10	80	Steel products Landfill
Fittings, furnishings and equipment	External Door - SolidCoreTimber/WoodenJam/Painted (m2) (External Door - SolidCoreTimber/WoodenJam/Painted)	Door Hardware (Handles, Hinges, Locks)	Steel | Stainless | Unspecified | Industry Average	40	6.516	kg	5	0.5	42	80	Steel products Landfill
Fittings, furnishings and equipment	External Glass Sliding Door (m2 incl. hardware) (External Glass Sliding Door (m2, incl. hardware))	Door Hardware (Handles, Hinges, Locks)	Steel | Stainless | Unspecified | Industry Average	40	0.8571429	kg	5	0.5	150	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Fittings, furnishings and equipment	Internal Door - HollowCoreTimber/WoodenJam/painted (m2) (Internal Door - HollowCoreTimber/WoodenJam/painted (m2))	Door Hardware (Handles, Hinges, Locks)	Steel | Stainless | Unspecified | Industry Average	40	11	kg	5	0.5	42	80	Steel products Landfill
General fittings, furnishings and equipment	Communications, residential	Light Fittings	Plastics | General | Unspecified | Industry Average	0	0.25	kg	20	0.5	20	0	Plastics Landfill
General fittings, furnishings and equipment	Communications, residential	Light Fittings	Steel | General | Unspecified | Industry Average	40	0.5	kg	5	0.5	20	80	Steel products Landfill
General fittings, furnishings and equipment	Lighting Residential LED Med Natural Light (Lighting Residential LED Med Natural Light)	Light Globes For Internal Fittings	Finished Products | Electrical Goods | Light Fittings | Fluorescent Globes | Compact | Industry Average	0	1.9695	kg	5	0.5	10	0	No Disposal Process
General fittings, furnishings and equipment	Lighting Residential LED Med Natural Light (Lighting Residential LED Med Natural Light)	Light Fittings	Glass | Flat Glass | Industry Average	0	2.925	kg	5	0.5	15	0	Glass Land Fill
General fittings, furnishings and equipment	Lighting Residential LED Med Natural Light (Lighting Residential LED Med Natural Light)	Light fitting	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	40	5.85	kg	5	0.5	15	80	Garden waste Landfill
Ceiling finishes	Ceiling Lining (Soffit) - medium density fibrecement (6mm)	acrylic adhesive	Resins and Adhesives | Epoxy Resin | Industry Average	0	458.4	Count	20	0.5	50	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Ceiling finishes	Ceiling Lining (Soffit) - medium density fibrecement (6mm)	Screws	Steel | General | Unspecified | Industry Average	40	0.14325	kg	5	0.5	50	80	Steel products Landfill
Cornices & Shadowlines	Wall Finish - MDF Skirtings (m)	Skirting Boards MDF 25mm x 150mm	Timber | Medium Density Fibreboard (MDF) | Industry Average	0	50.033333	Linear length Calculation	15	0.5	30	0	Wood Landfill
Cornices & Shadowlines	Wall Finish - MDF Skirtings (m)	Skirting Boards MDF 25mm x 150mm	Timber | Medium Density Fibreboard (MDF) | Industry Average	0	96.941667	Linear length Calculation	15	0.5	30	0	Wood Landfill
Cornices & Shadowlines	Wall Finish - Plaster Cornices (m)	Cornices 25mm x 200mm	Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	0	10.006667	Area Calculation	7.5	0.5	51	0	Inert Waste Landfill
Cornices & Shadowlines	Wall Finish - Plaster Cornices (m)	Cornices 25mm x 200mm	Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	0	19.388333	Area Calculation	7.5	0.5	51	0	Inert Waste Landfill
Finishes to floors	Floor Covering - Carpet (glue down/Nylon) (Floor Covering - Carpet (glue down/Nylon))	Carpet	Carpets and Floor Coverings | Carpet | Nylon | Medium Use | Industry Average	0	48.7	m2 (Default)	20	0.5	10	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Finishes to floors	Floor Covering - Carpet (glue down/Nylon) (Floor Covering - Carpet (glue down/Nylon))	Nylon Underlay	Carpets and Floor Coverings | Underlay | Nylon | Industry Average	0	48.7	m2 (Default)	20	0.5	10	0	Plastics Landfill
Finishes to floors	Floor Covering - Carpet (glue down/Nylon) (Floor Covering - Carpet (glue down/Nylon))	Glue	Resins and Adhesives | Urea Formaldehyde | Industry Average	0	9.74	kg	20	0.5	10	0	No Disposal Process
Finishes to floors	Floor Covering - Tiles (ceramic/2mm) (Floor Covering - Tiles (ceramic/2mm))	Tile grout	Cements and Limes | Portland Cement | Unspecified | Industry Average	0	16	Count	5	0.5	75	0	Inert Waste Landfill
Finishes to floors	Floor Covering - Tiles (ceramic/2mm) (Floor Covering - Tiles (ceramic/2mm))	Floor tiles	Ceramics | Ceramic Tiles | Industry Average	0	16	Count	15	0.5	30	0	Inert Waste Landfill
Finishes to floors	Floor Covering - Tiles (ceramic/2mm) (Floor Covering - Tiles (ceramic/2mm))	Sealant	Resins and Adhesives | Urea Formaldehyde | Industry Average	0	6.4	kg	20	0.5	15	0	Plastics Landfill
Finishes to floors	Floor Covering - Tiles (ceramic/2mm, no ppl)	Tile grout	Cements and Limes | Portland Cement | Unspecified | Industry Average	0	79	Count	5	0.5	75	0	Inert Waste Landfill
Finishes to floors	Floor Covering - Tiles (ceramic/2mm, no ppl)	Floor tiles	Ceramics | Ceramic Tiles | Industry Average	0	79	Count	15	0.5	30	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Finishes to floors	Floor Covering - Tiles (ceramic/2mm, no ppl)	Sealant	Resins and Adhesives | Urea Formaldehyde | Industry Average	0	31.6	kg	20	0.5	15	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	12.520842	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	12.520842	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	12.520842	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	24.259652	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	24.259652	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	24.259652	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	0.1252084	kg	5	0.5	17.5	80	Steel products Landfill
Paint - Walls	Internal Finish - Cornices Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified |	40	0.2425965	kg	5	0.5	17.5	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Industry Average								
Paint - Walls	Internal Finish - Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	157.4	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	157.4	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	157.4	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	120.08	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	120.08	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	120.08	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	232.66	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	232.66	m2 (Default)	15	0.5	50	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Paint - Walls	Internal Finish - Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	232.66	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	36.96	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	36.96	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	36.96	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	191	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	191	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	191	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	1.574	kg	5	0.5	17.5	80	Steel products Landfill
Paint - Walls	Internal Finish - Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry	40	1.2008	kg	5	0.5	17.5	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Average								
Paint - Walls	Internal Finish - Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	2.3266	kg	5	0.5	17.5	80	Steel products Landfill
Paint - Walls	Internal Finish - Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	0.3696	kg	5	0.5	17.5	80	Steel products Landfill
Paint - Walls	Internal Finish - Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	1.91	kg	5	0.5	17.5	80	Steel products Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	8.7558333	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	8.7558333	m2 (Default)	15	0.5	50	0	Plastics Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	8.7558333	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	16.964792	m2 (Default)	15	0.5	10	0	Plastics Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	16.964792	m2 (Default)	15	0.5	50	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	16.964792	m2 (Default)	15	0.5	20	0	Plastics Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	0.0875583	kg	5	0.5	17.5	80	Steel products Landfill
Paint - Walls	Internal Finish - Skirtings Paint (standard)	Consumables (paint tins, rollers etc)	Steel | General | Unspecified | Industry Average	40	0.1696479	kg	5	0.5	17.5	80	Steel products Landfill
Wall finishes	Internal Finish - Plaster Render (13mm)	10mm Pre-plaster float	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	120.08	Count	10	0.5	39	0	Inert Waste Landfill
Wall finishes	Internal Finish - Plaster Render (13mm)	10mm Pre-plaster float	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	232.66	Count	10	0.5	39	0	Inert Waste Landfill
Wall finishes	Internal Finish - Plaster Render (13mm)	13mm Plaster Render	Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	0	120.08	Count	7.5	0.5	39	0	Inert Waste Landfill
Wall finishes	Internal Finish - Plaster Render (13mm)	13mm Plaster Render	Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry	0	232.66	Count	7.5	0.5	39	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Average								
Communication, security and control systems	Communications, residential	Copper wire 5mm	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	20	Count	7.5	0.5	30	48	Copper Landfill
Communication, security and control systems	Communications, residential	Plastic associated with electrical wire and fittings	Plastics | General | Unspecified | Industry Average	0	20	Count	20	0.5	30	0	Plastics Landfill
Electrical installations	Solar PV System - Witchcliffe (SAM 1kWp, tilt 34d, azi 0d)	Frames	Aluminium | General | Industry Average	35	330	kg	1	0.5	50	57.33	Aluminium Landfill
Electrical installations	Solar PV System - Witchcliffe (SAM 1kWp, tilt 34d, azi 0d)	Inverter and cables etc	Finished Products | Electrical Goods | Inverter | Industry Average	0	66	kg	15	0.5	10	0	inverters Landfill
Electrical installations	Solar PV System - Witchcliffe (SAM 1kWp, tilt 34d, azi 0d)	Panels	Finished Products | Electrical Goods | Solar PV Panels | Monocystalline | Unspecified | Industry Average	0	42.24	m2 (Default)	2	0.5	25	0	Non-ferrous metals Landfill
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	Pump motor	Finished Products | Electrical Goods | Electric Motors | Industry Average (# unit equals $	0	10	kg	5	0.5	15	0	Electric motor Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Spent)								
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	Pump control unit	Finished Products | Electrical Goods | Electronics For Control Unit | Industry Average (# unit equals $ Spent)	0	0.05	kg	5	0.5	7.5	0	No Disposal Process
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	Fittings	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	1	kg	7.5	0.5	30	48	Copper Landfill
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	Tank liner 2 x 44kL tanks	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	0	77	kg	5	0	20	20	Plastics Landfill
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	2 x 44L rainwater tanks, 36m2 1mm Zincform steel	Steel | Coated Sheet | Galvanised (zinc coated) | Industry Average	40	1200	kg	5	0	20	80	No Disposal Process
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	Pressure equalisation vessel	Steel | General | Unspecified | Industry Average	40	5	kg	5	0.5	10	80	Steel products Landfill
Sanitary installations	88kL Rainwater tanks and Pump for Residence (2x44kL, steel) (WEV)	Pump wet end	Steel | Stainless | Unspecified |	40	2	kg	5	0.5	15	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Industry Average								
Sanitary installations	External timber deck (Alfresco) (External timber deck (Alfresco))	Drainage pipes	Plastics | Polyvinyl Chloride (PVC) | PVC Pipe | Industry Average	5	8.4	kg	20	0.5	30	20	Plastics Landfill
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	Concrete tile for hot water system	Concrete | Reinforced | 1.0% Reinforcement | 20 MPa | Industry Average	0	0.0125	m3	10	0.5	50	0	Inert Waste Landfill
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	Insulation	Insulation | Rigid Foams and Boards | Polyurethane | Industry Average	0	5.7	kg	15	0.5	20	0	Plastics Landfill
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	Brass parts	Metals (excluding steel and Aluminium) | Brass | Industry Average	29	2.6	kg	7.5	0	20	48	Non-ferrous metals Landfill
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	Associated Plumbing for HWS	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	10	kg	7.5	0.5	50	48	Copper Landfill
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	Galvanised sheet	Steel | Coated Sheet | Galvanised (zinc coated) | Industry Average	40	13.4	kg	10	0	20	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	Steel parts	Steel | General | Unspecified | Industry Average	40	4.2	kg	5	0	20	80	Steel products Landfill
Sanitary installations	HWS - Heat Pump Hot Water System (315L, CO2, high COP)	316 Stainless steel tank	Steel | Stainless | Unspecified | Industry Average	40	44	kg	7	0	20	80	Steel products Landfill
Sanitary installations	Plumbing Water and Sewerage Connection Residential (Plumbing, Water and Sewerage Connection, Residential)	Copper pipe (28mm diam) water supply from mains	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	40	Count	7.5	0.5	47	48	Copper Landfill
Sanitary installations	Plumbing Water and Sewerage Connection Residential (Plumbing, Water and Sewerage Connection, Residential)	Sewer pipe (210 diam)	Plastics | Polyvinyl Chloride (PVC) | PVC Pipe | Industry Average	5	1.78	Count	20	0.5	36	20	Plastics Landfill
Sanitary installations	Plumbing Water and Sewerage Connection Residential (Plumbing, Water and Sewerage Connection, Residential)	Hardware (pressure limiting valve, mains tap etc)	Steel | Stainless | Unspecified | Industry Average	40	0.5	kg	5	0.5	47	80	Steel products Landfill
Sanitary installations	Plumbing, Water and Sewerage Connection, Residential	Copper pipe (28mm diam) water supply from mains	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	40	Count	7.5	0.5	47	48	Copper Landfill
Sanitary installations	Plumbing, Water and Sewerage Connection, Residential	Sewer pipe (210 diam)	Plastics | Polyvinyl Chloride (PVC) | PVC Pipe | Industry Average	5	1.78	Count	20	0.5	36	20	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Sanitary installations	Plumbing, Water and Sewerage Connection, Residential	Hardware (pressure limiting valve, mains tap etc)	Steel | Stainless | Unspecified | Industry Average	40	0.5	kg	5	0.5	47	80	Steel products Landfill
Services equipment	Residential UV Water Treatment System (45W)	Aluminium mounting bracket	Aluminium | Sheet - Powder-coated | Industry Average	35	1	kg	1	0	10	57.33	Aluminium Landfill
Services equipment	Residential UV Water Treatment System (45W)	Electronics for UV sterilisation unit	Finished Products | Electrical Goods | Electronics For Control Unit | Industry Average (# unit equals $ Spent)	0	0.05	kg	5	0	5	0	No Disposal Process
Services equipment	Residential UV Water Treatment System (45W)	Fluroescent lamp/globe for UV steriliser	Finished Products | Electrical Goods | Light Fittings | Fluorescent Globes | Compact | Industry Average	0	1	# (Default)	5	0	1	0	Fluorescent lamps Disposal
Services equipment	Residential UV Water Treatment System (45W)	Water Filter Cartridges, large	Plastics | Polypropylene | Injection Moulding | Industry Average	0	0.4	kg	5	0	1	0	Plastics Landfill
Services equipment	Residential UV Water Treatment System (45W)	Filter housings	Plastics | Polypropylene | Injection Moulding | Industry Average	0	1.8	kg	5	0	10	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Services equipment	Residential UV Water Treatment System (45W)	UV sterilisation unit	Steel | Stainless | Unspecified | Industry Average	40	2	kg	5	0	10	80	Steel products Landfill
Space heating and air conditioning	Air Source Heat Pump Embodied	Refrigerant	Gases | Refrigerants | CO2 | Industry Average	0	1.44	kg	2	0.5	20	0	Refrigerant Gas Carbon dioxide loss
Space heating and air conditioning	Air Source Heat Pump Embodied	Pipe Insulation	Insulation | Rigid Foams and Boards | Polyethylene | Industry Average	0	1	kg	15	0.5	20	0	Plastics Landfill
Space heating and air conditioning	Air Source Heat Pump Embodied	Airconditioning External Unit	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	5	kg	7.5	0.5	20	48	Copper Landfill
Space heating and air conditioning	Air Source Heat Pump Embodied	Pipes	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	2.5	kg	7.5	0.5	40	48	Copper Landfill
Space heating and air conditioning	Air Source Heat Pump Embodied	Airconditioning External Unit	Plastics | General | Unspecified | Industry Average	0	10	kg	20	0.5	20	0	Plastics Landfill
Space heating and air conditioning	Air Source Heat Pump Embodied	Airconditioning External Unit	Rubber | Synthetic | Industry Average	0	2	kg	10	0.5	20	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Space heating and air conditioning	Air Source Heat Pump Embodied	Airconditioning External Unit	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	40	2	kg	5	0.5	20	80	No Disposal Process
Space heating and air conditioning	Air Source Heat Pump Embodied	Airconditioning External Unit	Steel | General | Unspecified | Industry Average	40	10	kg	5	0.5	20	80	Steel products Landfill
Space heating and air conditioning	Air Source Heat Pump Embodied	Airconditioning External Unit	Steel | General | Unspecified | Industry Average	40	16	kg	5	0.5	20	80	Steel products Landfill
Space heating and air conditioning	Ceiling Fans Embodied	Copper electrical wire	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	12	kg	7.5	0.5	150	48	Copper Landfill
Space heating and air conditioning	Ceiling Fans Embodied	Plastic associated with electrical wire and fittings	Plastics | General | Unspecified | Industry Average	0	9	kg	20	0.5	20	0	Plastics Landfill
Space heating and air conditioning	Ceiling Fans Embodied	Fan rotor and blades	Steel | General | Unspecified | Industry Average	40	12	kg	5	0.5	25	80	Steel products Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Refrigerant	Gases | Refrigerants | 410a | Industry Average	0	5.1732	kg	2	0.5	20	0	Refrigerant Gas R410a Loss
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Pipe Insulation	Insulation | Rigid Foams and Boards | Polyethylene | Industry Average	0	1.79625	kg	15	0.5	20	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning External Unit	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	8.98125	kg	7.5	0.5	20	48	Copper Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning Internal Unit	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	8.98125	kg	7.5	0.5	20	48	Copper Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Pipes	Metals (excluding steel and Aluminium) | Copper | Industry Average	29	8.98125	kg	7.5	0.5	40	48	Copper Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning External Unit	Plastics | General | Unspecified | Industry Average	0	17.9625	kg	20	0.5	20	0	Plastics Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning Internal Unit	Plastics | General | Unspecified | Industry Average	0	10.7775	kg	20	0.5	20	0	Plastics Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning External Unit	Rubber | Synthetic | Industry Average	0	3.5925	kg	10	0.5	20	0	Plastics Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning Internal Unit and Hoses	Rubber | Synthetic | Industry Average	0	17.9625	kg	10	0.5	20	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning External Unit	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	40	3.5925	kg	5	0.5	20	80	No Disposal Process
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning External Unit	Steel | General | Unspecified | Industry Average	40	17.9625	kg	5	0.5	20	80	Steel products Landfill
Space heating and air conditioning	HVAC Air Source Heat Pump Embodied (multi-split)	Airconditioning External Unit	Steel | General | Unspecified | Industry Average	40	28.74	kg	5	0.5	20	80	Steel products Landfill
Lowest floor construction	Concrete Floor - 100mm slab on ground (including 30MPa concrete concrete pump SL62 reo mesh membrane sand bed compaction) (Concrete Floor - 100mm slab on ground (including 30MPa concrete, concrete pump, SL62 reo mesh, membrane, sand bed, compaction))	Impermeable Membrane	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	5	98.7	Area Calculation	20	0.5	150	20	Plastics Landfill
Lowest floor construction	Concrete Floor - 100mm slab on ground (including 30MPa concrete concrete pump SL82 reo mesh membrane sand bed compaction) (Concrete Floor - 100mm slab on ground (including 30MPa concrete, concrete pump, SL82 reo mesh, membrane, sand bed, compaction))	Impermeable Membrane	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	5	175.35	Area Calculation	20	0.5	150	20	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Lowest floor construction	External timber deck (Alfresco) (External timber deck (Alfresco))	Misc fixings	Steel | General | Unspecified | Industry Average	40	2.8	kg	5	0.5	30	80	Steel products Landfill
Lowest floor construction	External timber deck (Alfresco) (External timber deck (Alfresco))	90mm x 90mm pine bearers	Timber | Softwood | Industry Average	0	0.126	m3	15	0.5	30	0	Wood Landfill
Lowest floor construction	External timber deck (Alfresco) (External timber deck (Alfresco))	90mm x 4500 pine joists	Timber | Softwood | Industry Average	0	0.3248	m3	15	0.5	30	0	Wood Landfill
Lowest floor construction	External timber deck (Alfresco) (External timber deck (Alfresco))	90mm x 19mm pine decking with 4mm spacing	Timber | Softwood | Industry Average	0	0.5824	m3	15	0.5	30	0	Wood Landfill
Lowest floor construction	Formwork - Floors (substructure)	Formwork for floors	Timber | Plywood | Unspecified | Industry Average	0	1.2024	m3	15	0.5	150	0	Wood Landfill
Lowest floor construction	Formwork - Floors (substructure)	Formwork for floors	Timber | Plywood | Unspecified | Industry Average	0	0.6768	m3	15	0.5	150	0	Wood Landfill
Lowest floor construction	Poured Concrete - Floors Substructure, 30MPa	Concrete poured	Concrete | Unreinforced | 30 MPa | Industry Average	0	16.7	m3	10	0.5	150	0	Inert Waste Landfill
Lowest floor construction	Poured Concrete - Floors Substructure, 30MPa	Concrete poured	Concrete | Unreinforced | 30 MPa | Industry Average	0	9.4	m3	10	0.5	150	0	Inert Waste Landfill
Lowest floor construction	Reinforcement Bar - Floor Substructure (kg)	steel reinforcement bars (floor)	Steel | General | Unspecified | Industry Average	40	668	kg	5	0.5	150	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Lowest floor construction	Reinforcement Bar - Floor Substructure (kg)	steel reinforcement bars (floor)	Steel | General | Unspecified | Industry Average	40	235	kg	5	0.5	150	80	Steel products Landfill
Standard foundations	External timber deck (Alfresco) (External timber deck (Alfresco))	Concrete fill for stumps	Concrete | Unreinforced | Unspecified | Industry Average	0	0.6356	m3	10	0.5	100	0	Inert Waste Landfill
Standard foundations	External timber deck (Alfresco) (External timber deck (Alfresco))	100mm x 100mm Cypress stumps	Timber | General | Industry Average	0	0.182	m3	15	0.5	50	0	Wood Landfill
Standard foundations	External timber deck (Alfresco) (External timber deck (Alfresco))	200mm x 50mm pine Sole plate	Timber | Softwood | Industry Average	0	0.0308	m3	15	0.5	50	0	Wood Landfill
Standard foundations	Formwork (Foundations)	Formwork timber footings	Timber | Plywood | Unspecified | Industry Average	0	0.648	m3	15	0.5	100	0	Wood Landfill
Standard foundations	Foundations - Sand Bed	80mm Sandbed	Bulk Aggregates Sands and Soils | Sand (Compacted) | Unspecified | Industry Average	0	13.36	Count	15	0.5	150	0	Inert Waste Landfill
Standard foundations	Foundations - Sand Bed	80mm Sandbed	Bulk Aggregates Sands and Soils | Sand (Compacted) | Unspecified | Industry Average	0	7.52	Count	15	0.5	150	0	Inert Waste Landfill
Standard foundations	Poured Concrete - Foundations, 40MPa	Pour Concrete Foundations	Concrete | Unreinforced | 40 MPa | Industry Average	0	9	m3	10	0.5	150	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Standard foundations	Reinforcement Bar - foundations (kg)	steel reinforcement bars (foundation)	Steel | General | Unspecified | Industry Average	40	2851.2	kg	5	0.5	150	80	Steel products Landfill
Substructure	Sand infill & compaction (Sand infill & compaction)	Sand infill	Bulk Aggregates Sands and Soils | Sand (Compacted) | Unspecified | Industry Average	0	6.6	m3	15	0	150	0	Inert Waste Landfill
Balconies	External timber deck (Alfresco) (External timber deck (Alfresco))	Decking stain	Paints and Finishes | Wood Stains and Finishes | General | Industry Average	0	28	m2 (Default)	15	0.5	10	0	Plastics Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	Plaster-based cement for back-blocking	Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	0	3462.8	Count	7.5	0.5	45	0	Inert Waste Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	Plaster-based cement for back-blocking	Plaster and Gypsum Derived Products | Plaster | Unspecified | Industry Average	0	4202	Count	7.5	0.5	45	0	Inert Waste Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	12mm back-blocking plasterboard	Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	0	157.4	Count	15	0.5	45	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	12mm plasterboard	Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	0	157.4	m2 (Default)	15	0.5	45	0	Inert Waste Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	12mm back-blocking plasterboard	Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	0	191	Count	15	0.5	45	0	Inert Waste Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	12mm plasterboard	Plaster and Gypsum Derived Products | Plaster Board | 12mm Sheets | Industry Average	0	191	m2 (Default)	15	0.5	45	0	Inert Waste Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	acrylic adhesive	Resins and Adhesives | Epoxy Resin | Industry Average	0	2518.4	Count	20	0.5	45	0	Plastics Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	acrylic adhesive	Resins and Adhesives | Epoxy Resin | Industry Average	0	3056	Count	20	0.5	45	0	Plastics Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	Screws	Steel | General | Unspecified | Industry Average	40	0.787	kg	5	0.5	45	80	Steel products Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	Screws	Steel | General | Unspecified | Industry Average	40	0.955	kg	5	0.5	45	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	Timber ceiling battens	Timber | Softwood | Industry Average	0	349.77428	Count	15	0.5	45	0	Wood Landfill
Ceiling finishes	Ceiling Lining - Plasterboard (12mm)	Timber ceiling battens	Timber | Softwood | Industry Average	0	424.4402	Count	15	0.5	45	0	Wood Landfill
External doors	External Door - SolidCoreTimber/WoodenJam/Painted (m2) (External Door - SolidCoreTimber/WoodenJam/Painted)	Door	Timber | General | Industry Average	0	228.06	kg	15	0.5	42	0	Wood Landfill
External doors	External Door - SolidCoreTimber/WoodenJam/Painted (m2) (External Door - SolidCoreTimber/WoodenJam/Painted)	Door Jam	Timber | General | Industry Average	0	45.612	Count	15	0.5	42	0	Wood Landfill
External doors	External Glass Sliding Door (m2 incl. hardware) (External Glass Sliding Door (m2, incl. hardware))	Steel sliders and hardware	Steel | Stainless | Unspecified | Industry Average	40	5.3142857	kg	5	0.5	150	80	Steel products Landfill
External enclosing walls above ground level	External Finish - 13mm Render (Cement)	13mm Cement Render	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	120.08	Area Calculation	10	0.5	53	0	Inert Waste Landfill
External enclosing walls above ground level	External Finish - 13mm Render (Cement)	13mm Cement Render	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	64.68	Area Calculation	10	0.5	53	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
External enclosing walls above ground level	External Finish - 13mm Render (Cement)	Sealant	Plastics | Acrylic | Unspecified | Industry Average	0	11.2575	kg	20	0.5	53	0	Plastics Landfill
External enclosing walls above ground level	External Finish - 13mm Render (Cement)	Sealant	Plastics | Acrylic | Unspecified | Industry Average	0	6.06375	kg	20	0.5	53	0	Plastics Landfill
External enclosing walls above ground level	Masonry Wall - Double Brick (90/50/90) paint concrete render ext plaster render int (no insulation no foundation no plasterboard) [WEV] (Masonry Wall - Double Brick (110/50/110) paint, concrete render ext, plaster render int (no insulation, no foundation,	Flashing	Aluminium | General | Industry Average	35	23.4156	kg	1	0.5	150	57.33	Aluminium Landfill
External enclosing walls above ground level	Masonry Wall - Double Brick (90/50/90) paint concrete render ext plaster render int (no insulation no foundation no plasterboard) [WEV] (Masonry Wall - Double Brick (110/50/110) paint, concrete render ext, plaster render int (no insulation, no foundation,	Brick ties	Steel | General | Unspecified | Industry Average	40	36.024	kg	5	0.5	150	80	Steel products Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110) concrete render ext (no insulation no foundation) [WEV] (Masonry Wall - Single Brick (110) concrete render ext, (no insulation, no foundation) [WEV])	Flashing	Aluminium | General | Industry Average	35	6.3063	kg	1	0.5	150	57.33	Aluminium Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
External enclosing walls above ground level	Masonry Wall - Single Brick (110) concrete render ext (no insulation no foundation) [WEV] (Masonry Wall - Single Brick (110) concrete render ext, (no insulation, no foundation) [WEV])	Brick ties	Steel | General | Unspecified | Industry Average	40	9.702	kg	5	0.5	150	80	Steel products Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110) internal (paint plaster render int no insulation no foundation no plasterboard) [WEV] (Masonry Wall - Single Brick (110) internal (paint, plaster render int, no insulation, no foundation, no plasterboard) [WEV])	Flashing	Aluminium | General | Industry Average	35	22.68435	kg	1	0.5	150	57.33	Aluminium Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110) internal (paint plaster render int no insulation no foundation no plasterboard) [WEV] (Masonry Wall - Single Brick (110) internal (paint, plaster render int, no insulation, no foundation, no plasterboard) [WEV])	Brick ties	Steel | General | Unspecified | Industry Average	40	34.899	kg	5	0.5	150	80	Steel products Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	110mm Face Bricks	Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	0	11635.752	Count	5	0.5	150	0	Inert Waste Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	110mm Face Bricks	Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry	0	5636.1885	Count	5	0.5	150	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Average								
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	110mm Face Bricks	Bricks, Blocks and Pavers | Clay Bricks and Pavers | Unspecified | Industry Average	0	1566.873	Count	5	0.5	150	0	Inert Waste Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	Mortar	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	4.0445346	m3	10	0.5	150	0	Inert Waste Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	Mortar	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	1.9591135	m3	10	0.5	150	0	Inert Waste Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	Mortar	Cements and Limes | Mortars and Renders | 1 cement : 4 sand | Industry Average	0	0.5446379	m3	10	0.5	150	0	Inert Waste Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	Waterproof membrane 1mm	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	5	30.02	Area Calculation	20	0.5	150	20	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	Waterproof membrane 1mm	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	5	14.54125	Area Calculation	20	0.5	150	20	Plastics Landfill
External enclosing walls above ground level	Masonry Wall - Single Brick (110mm)	Waterproof membrane 1mm	Plastics | High Density Polyethylene (HDPE) | Unspecified | Industry Average	5	4.0425	Area Calculation	20	0.5	150	20	Plastics Landfill
External enclosing walls above ground level	Timber beam 300x75	Timber structural beam	Timber | General | Industry Average	0	27.45	Count	15	0.5	69	0	Wood Landfill
External Paint, Textures and Renders	External Finish - Paint (SuperStructure)	Top Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	21.89376	m2 (Default)	15	0.5	10	0	Plastics Landfill
External Paint, Textures and Renders	External Finish - Paint (SuperStructure)	Primer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	21.89376	m2 (Default)	15	0.5	50	0	Plastics Landfill
External Paint, Textures and Renders	External Finish - Paint (SuperStructure)	Undercoat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	21.89376	m2 (Default)	15	0.5	20	0	Plastics Landfill
External Paint, Textures and Renders	External Finish - Paint (SuperStructure)	Consumables (Paint tins, rollers, etc)	Steel | General | Unspecified | Industry Average	40	0.2189376	kg	5	0.5	17.5	80	Steel products Landfill
External Paint, Textures and Renders	Timber Solar Shade Awning (no covering) (Timber Solar Shade Awning (no covering))	Sealer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	13.656	m2 (Default)	15	0.5	50	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
External Paint, Textures and Renders	Timber Solar Shade Awning (no covering) (Timber Solar Shade Awning (no covering))	Paint Final Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	13.656	m2 (Default)	15	0.5	15	0	Plastics Landfill
External Paint, Textures and Renders	Timber Solar Shade Awning (no covering) (Timber Solar Shade Awning (no covering))	Paint - Undercoat	Paints and Finishes | Unspecified | 2 Coats | Industry Average	0	13.656	m2 (Default)	15	0.5	25	0	Plastics Landfill
External Paint, Textures and Renders	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Sealer	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	92.178	m2 (Default)	15	0.5	50	0	Plastics Landfill
External Paint, Textures and Renders	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Paint Final Coat	Paints and Finishes | Unspecified | 1 Coat | Industry Average	0	92.178	m2 (Default)	15	0.5	15	0	Plastics Landfill
External Paint, Textures and Renders	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Paint - Undercoat	Paints and Finishes | Unspecified | 2 Coats | Industry Average	0	92.178	m2 (Default)	15	0.5	25	0	Plastics Landfill
External Paint, Textures and Renders	Wood Stain External Finish	wood stain final coat (6m2/litre)	Paints and Finishes | Wood Stains and Finishes | General | Industry Average	0	0.0014976	m3	15	0.5	7	0	Plastics Landfill
External Paint, Textures and Renders	Wood Stain External Finish	wood stain first coat (6m2/litre)	Paints and Finishes | Wood Stains and Finishes | General | Industry Average	0	0.0014976	kg	15	0.5	15	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
External soffits	Ceiling Lining (Soffit) - medium density fibrecement (6mm)	6mm soffit panel	Fibre Board | Fibre Cement | Medium Density. 1250 kg/t | Industry Average	0	28.65	Count	15	0.5	50	0	Inert Waste Landfill
External windows	Windows Residential Aluminium Single Glaze fly screen (Windows, Residential Aluminium Single Glaze, fly screen)	Ali Windows and Sliding Doors	Windows | Aluminium Framed | No Thermal Break | Single Glaze | Domestic 50% Opening | Industry Average	0	7.8	m2 (Default)	2	0.5	44	0	Inert Waste Landfill
External windows	Windows Residential Aluminium Single Glaze fly screen (Windows, Residential Aluminium Single Glaze, fly screen)	Ali Windows and Sliding Doors	Windows | Aluminium Framed | No Thermal Break | Single Glaze | Domestic 50% Opening | Industry Average	0	4.26	m2 (Default)	2	0.5	44	0	Inert Waste Landfill
External windows	Windows Residential Aluminium Single Glaze fly screen (Windows, Residential Aluminium Single Glaze, fly screen)	Ali Windows and Sliding Doors	Windows | Aluminium Framed | No Thermal Break | Single Glaze | Domestic 50% Opening | Industry Average	0	0.5	m2 (Default)	2	0.5	44	0	Inert Waste Landfill
External windows	Windows single glazed aluminium frame individual components	aluminium frame	Aluminium | General | Industry Average	35	2.7428571	kg	1	0.5	44	57.33	Aluminium Landfill
External windows	Windows single glazed aluminium frame individual components	window pane	Glass | Flat Glass | Industry Average	0	22.071429	kg	5	0.5	44	0	Glass Land Fill
External windows	Windows single glazed aluminium frame individual components	thermal break	Rubber | Synthetic | Industry	0	0.2742857	kg	10	0.5	44	0	Plastics Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Average								
Frame	Structure - Timber Truss 10m (0.24x0.025x10)	Bottom chord of trussx2 0.24x0.025x10	Timber | General | Industry Average	0	0.853512	m3	15	0	84	0	Wood Landfill
Frame	Structure - Timber Truss 10m (0.24x0.025x10)	Truss Stiffener Platesx8 (0.24x0.25x1.35	Timber | General | Industry Average	0	0.2304482	m3	15	0	84	0	Wood Landfill
Frame	Structure - Timber Truss 10m (0.24x0.025x10)	Truss Uprightsx18 (o.24x0.025x0.5)	Timber | General | Industry Average	0	0.1920402	m3	15	0	84	0	Wood Landfill
Frame	Structure - Timber Truss 10m (0.24x0.025x10)	Bottom chord of trussx2 0.24x0.025x10	Timber | General | Industry Average	0	2.65872	m3	15	0	84	0	Wood Landfill
Frame	Structure - Timber Truss 10m (0.24x0.025x10)	Truss Stiffener Platesx8 (0.24x0.25x1.35	Timber | General | Industry Average	0	0.7178544	m3	15	0	84	0	Wood Landfill
Frame	Structure - Timber Truss 10m (0.24x0.025x10)	Truss Uprightsx18 (o.24x0.025x0.5)	Timber | General | Industry Average	0	0.598212	m3	15	0	84	0	Wood Landfill
Frame	Timber post, hardwood, 120mm x 120mm, finished	Hardwood posts 120mm x 120mm	Timber | General | Industry Average	0	15.6	Linear length Calculation	15	0	110	0	Wood Landfill
Insulation	Bulk Insulation - Rockwool (R6.0)	R6.0 mineral wool batts (1.5x R4.0 quantity)	Insulation | Blankets and Batts | Mineral Wool | Blanket | R 4.0 | Industry Average	0	286.5	m2 (Default)	2	0.5	50	0	Inert Waste Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Internal doors	Internal Door - HollowCoreTimber/WoodenJam/painted (m2) (Internal Door - HollowCoreTimber/WoodenJam/painted (m2))	Hollow Core	Timber | General | Industry Average	0	264	kg	15	0.5	42	0	Wood Landfill
Internal doors	Internal Door - HollowCoreTimber/WoodenJam/painted (m2) (Internal Door - HollowCoreTimber/WoodenJam/painted (m2))	Door Jam (300x25mm)	Timber | General | Industry Average	0	77	Linear length Calculation	15	0.5	42	0	Wood Landfill
Roof coverings	Covering - Steel Sheeting 0.42mm corrugated	0.48mm corrugated/CustomOrb sheet	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	40	301.93292	kg	5	0.5	80	80	Steel products Landfill
Roof coverings	Covering - Steel Sheeting 0.42mm corrugated	0.48mm corrugated/CustomOrb sheet	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	40	1038.6179	kg	5	0.5	80	80	Steel products Landfill
Roof coverings	Covering - Steel Sheeting 0.42mm corrugated	Fastenings	Steel | Stainless | Unspecified | Industry Average	40	0.61244	kg	5	0.5	80	80	Steel products Landfill
Roof coverings	Covering - Steel Sheeting 0.42mm corrugated	Fastenings	Steel | Stainless | Unspecified | Industry Average	40	2.10673	kg	5	0.5	80	80	Steel products Landfill
Roof coverings	Roof - TimberTruss/SteelSheeting/5°Pitch (no ceiling or insulation)	Tile valleys	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.56mm | Industry	40	4.0687	Count	5	0.5	50	80	Steel products Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Average								
Roof drainage	Gutter - steel	1m of 0.42mm thick Emline profile gutter	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.43mm | Industry Average	40	64.94	Count	5	0.5	80	80	Steel products Landfill
Roof drainage	Gutter - steel	Screws, bolts & fixings	Steel | Galvinised Structural | Industry Average	40	1.9482	kg	5	0.5	80	80	Steel products Landfill
Roof drainage	Roof - TimberTruss/SteelSheeting/5°Pitch (no ceiling or insulation)	Gutters and Down Pipes	Steel | Coated Sheet | Zinc Coated & Coloured Sheet 0.56mm | Industry Average	40	20.313	Count	5	0.5	50	80	Steel products Landfill
Roof structure	Structure - Timber Truss 10m (0.24x0.025x10)	Top chord of trussx2 0.24x0.025x10	Timber | General | Industry Average	0	0.853512	m3	15	0.5	84	0	Wood Landfill
Roof structure	Structure - Timber Truss 10m (0.24x0.025x10)	Top chord of trussx2 0.24x0.025x10	Timber | General | Industry Average	0	2.65872	m3	15	0.5	84	0	Wood Landfill
Security and Fly Screens	Fly Screen	Fly screen frame	Aluminium | General | Industry Average	35	3.9	kg	1	0.5	20	57.33	Aluminium Landfill
Security and Fly Screens	Fly Screen	Fly screen frame	Aluminium | General | Industry Average	35	2.13	kg	1	0.5	20	57.33	Aluminium Landfill
Security and Fly Screens	Fly Screen	Fly screen frame	Aluminium | General | Industry	35	0.25	kg	1	0.5	20	57.33	Aluminium Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
			Average								
Security and Fly Screens	Fly Screen	Flyscreen Mesh	Plastics | General | Unspecified | Industry Average	0	3.9	Count	20	0.5	20	0	No Disposal Process
Security and Fly Screens	Fly Screen	Flyscreen Mesh	Plastics | General | Unspecified | Industry Average	0	2.13	Count	20	0.5	20	0	No Disposal Process
Security and Fly Screens	Fly Screen	Flyscreen Mesh	Plastics | General | Unspecified | Industry Average	0	0.25	Count	20	0.5	20	0	No Disposal Process
Security and Fly Screens	Fly Screen	Flyscreen rubber spline	Rubber | Synthetic | Industry Average	0	1.95	kg	10	0.5	20	0	No Disposal Process
Security and Fly Screens	Fly Screen	Flyscreen rubber spline	Rubber | Synthetic | Industry Average	0	1.065	kg	10	0.5	20	0	No Disposal Process
Security and Fly Screens	Fly Screen	Flyscreen rubber spline	Rubber | Synthetic | Industry Average	0	0.125	kg	10	0.5	20	0	No Disposal Process
Solar/rain screening	Timber Solar Shade Awning (no covering) (Timber Solar Shade Awning (no covering))	Hardware	Steel | General | Unspecified | Industry Average	40	8	kg	5	0.5	75	80	Steel products Landfill
Solar/rain screening	Timber Solar Shade Awning (no covering) (Timber Solar Shade Awning (no covering))	Joists	Timber | Softwood | Industry Average	0	10.4	Count	15	0.5	75	0	Wood Landfill
Solar/rain screening	Timber Solar Shade Awning (no covering) (Timber Solar Shade Awning (no covering))	Shade Fins	Timber | Softwood | Industry Average	0	4.8	Count	15	0.5	75	0	Wood Landfill

Sub Category	Template	Description	Material Name	Recycle Content (%)	Quantity	Unit	Waste Factor (%)	Transport Losses (%)	Life Span (years)	Recycling Rate (%)	Disposal Method
Solar/rain screening	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Transparent Polycarbonate Sheeting	Plastics | Polycarbonate | Unspecified | Industry Average	0	29.7	Count	20	0.5		0	Plastics Landfill
Solar/rain screening	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Flashing	Steel | General | Unspecified | Industry Average	40	16.2	Count	5	0.5	75	80	Steel products Landfill
Solar/rain screening	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Hardware	Steel | General | Unspecified | Industry Average	40	54	kg	5	0.5	75	80	Steel products Landfill
Solar/rain screening	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Posts	Timber | General | Industry Average	0	27	Count	15	0.5	75	0	Wood Landfill
Solar/rain screening	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Joists	Timber | Softwood | Industry Average	0	70.2	Count	15	0.5	75	0	Wood Landfill
Solar/rain screening	Timber Solar Shade Awning or Pergola (Timber Solar Shade Awning or Pergola)	Shade Fins	Timber | Softwood | Industry Average	0	32.4	Count	15	0.5	75	0	Wood Landfill

8 APPENDIX C - ARCHITECTURAL PLANS

Please refer to the separate document for architectural plans of the building:

- WEV House for LCA Analysis.pdf (10/6/2019)
- LCA House with Dims.pdf (13/6/2019)

9 APPENDIX D – EN 15978 RESULTS SUMMARY TABLE

Table 44 EN 15978 Results summary table for the Base Case Design v2

Environmental Impact Category	Materials and Construction			Use Stage								End of Life Stage				Benefits and Loads Beyond the System Boundary	Total
	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B6+	B7	C1	C2	C3	C4	D	
GWP (kg CO2-eq)	6.55E+04	1.45E+04	4.73E+03	0.00E+00	8.19E+03	MNA	1.42E+05	MNA	-3.63E+05	7.31E+04	1.83E+04	0.00E+00	8.05E+03	0.00E+00	2.31E+04	-4.22E+04	-4.78E+04
ODP (kg CFC-11 eq)	1.62E-02	2.36E-03	4.73E-04	0.00E+00	4.66E-03	MNA	4.90E-02	MNA	-2.33E-03	4.69E-04	2.51E-04	0.00E+00	1.26E-03	0.00E+00	5.61E-04	-3.86E-04	7.26E-02
AP (kg SO2 eq.)	5.21E+02	9.21E+01	1.91E+01	0.00E+00	2.60E-01	MNA	7.44E+02	MNA	-6.53E+02	1.31E+02	3.56E+01	0.00E+00	5.00E+01	0.00E+00	1.11E+01	-1.34E+02	8.18E+02
EP (kg PO4--- eq)	1.75E+02	2.20E+01	4.10E+00	0.00E+00	4.84E-02	MNA	2.95E+02	MNA	-2.08E+02	4.19E+01	1.10E+01	0.00E+00	1.17E+01	0.00E+00	2.38E+00	-5.23E+01	3.03E+02
POCP (kg ethylene)	3.42E+01	2.77E+00	1.56E+00	0.00E+00	1.15E-02	MNA	3.71E+01	MNA	-1.71E+01	3.45E+00	2.14E+00	0.00E+00	1.54E+00	0.00E+00	2.52E+00	-8.85E+00	5.92E+01
ADPE (kg antimony)	1.66E+01	6.65E-01	6.40E-02	0.00E+00	3.86E-02	MNA	4.62E+01	MNA	-2.49E+00	5.01E-01	2.16E-01	0.00E+00	5.30E-01	0.00E+00	3.13E-02	-7.79E-01	6.16E+01
ADPF (MJ)	1.06E+06	2.24E+05	4.53E+04	0.00E+00	7.29E+02	MNA	1.47E+06	MNA	-4.69E+06	9.44E+05	2.34E+05	0.00E+00	1.25E+05	0.00E+00	5.70E+04	-4.98E+05	-1.03E+06