Study Report

SR351 [2016]

New Zealand whole-building whole-of-life framework: Development of datasheets to support building life cycle assessment

David Dowdell, Brian Berg, Nick Marston, Patricia Shaw, John Burgess, Johannes Roberti and Brendan White

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1222 Moonshine Rd, RD1, Porirua 5381
Private Bag 50 908, Porirua 5240
New Zealand
branz.nz

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Preface

In April 2013, BRANZ commenced research into development of a New Zealand whole-building whole-of-life framework. The purpose of the framework is to establish a level playing field for evaluation and reporting of the environmental impacts of building designs in comparison with an appropriate reference building, based on life cycle assessment (LCA). Initial focus is on offices.

This report has been developed under Research Stream 3 (RS3) within a programme of research to develop the framework. The aim of RS3 is to develop information and data to facilitate use of LCA at the building level. This information and reference data has been used as the basis for a set of New Zealand office buildings for which environmental indicators have been calculated.

Other reports published for the framework research are available on the BRANZ website at www.branz.co.nz/study_reports and include the following:

Berg, B. Dowdell, D. & Curtis, M. (2016). *New Zealand whole-building whole-of-life framework: Development of reference office buildings for use in early design*. BRANZ Study Report SR350. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. & Berg, B. (2016). *New Zealand whole-building whole-of-life framework: An overview*. BRANZ Study Report SR349. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2014). New Zealand whole building whole of life framework: Life cycle assessment-based indicators. BRANZ Study Report SR293. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2013). *Application of environmental profiling to whole building whole of life assessment – key features*. BRANZ Study Report SR276. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2013). *Application of environmental profiling to whole building whole of life assessment – a plan for New Zealand*. BRANZ Study Report SR275. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2012). *Review of how life cycle assessment is used in international building environmental rating tools – issues for consideration in New Zealand*. BRANZ Study Report SR272. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2012). *Evaluation of Environmental Choice New Zealand as a best practice ecolabel and comparison with the GBCA Framework*. BRANZ Study Report SR271. Judgeford, New Zealand: BRANZ Ltd.

Jaques, R., McLaren, J. & Nebel, B. (2011). *Environmental profiling of New Zealand building material products: Where to for the New Zealand building sector* BRANZ Discussion Paper. Judgeford, New Zealand: BRANZ Ltd.

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Finally, BRANZ would like to thank Massey University, in particular Sarah McLaren of the New Zealand Life Cycle Management Centre, and the Victoria University of Wellington, in particular Mike Donn of the School of Architecture, for their valuable contributions to this project.

Note

This report is intended for stakeholders with an interest in understanding the environmental impacts of the built environment through application of life cycle assessment (LCA), including government, architects, designers, engineers, quantity surveyors, specifiers, construction product manufacturers, importers, design and building information modelling (BIM) tool providers, LCA practitioners and researchers.

It has been developed primarily for application to design of new offices in New Zealand but may be helpful for other applications of building LCA.

New Zealand whole-building whole-of-life framework: Development of datasheets to support building life cycle assessment

BRANZ Study Report SR351

Author(s)

David Dowdell, Brian Berg, Nick Marston, Patricia Shaw, John Burgess, Johannes Roberti, Brendan White

Reference

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Abstract

BRANZ, with industry and research partners, has developed the New Zealand whole-building whole-of-life framework, which aims to provide resources to facilitate more consistent use of life cycle assessment (LCA) applied to buildings. This is especially important now that building LCA is recognised within the Innovation category of the Green Star building environmental rating tool.

To facilitate comparability between building LCAs, datasheets have been developed covering different parts of the building life cycle. The purpose of these datasheets is to help the development of consistent assumptions, inform development of scenarios (as defined in the standard EN 15978) and for filling of data gaps when carrying out building LCA. While the focus of currently available datasheets is on application to new-build offices at early (concept and preliminary) design, the data may be useful for other building LCA studies.

This report provides supporting information concerning the methods used to develop the datasheets. As more and better data becomes available, it is intended that the datasheets will be updated.

Keywords

Datasheet, energy, environment, LCA, LCAQuick, life cycle analysis, life cycle assessment, office, scenario, transport, waste, water, whole building, whole of life

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Acronyms and terms

ALCAS	Australian Life Cycle Assessment Society (www.alcas.asn.au)
BEES	Building Energy End-use Study (www.branz.co.nz/BEES)
BIM	building information model
BRE	Building Research Establishment (www.bre.co.uk)
BREEAM	BRE Environmental Assessment Method
building information model	A digital representation of the physical and functional characteristics of a building. As such, it serves as a shared knowledge resource for information about a building, forming a reliable basis for decisions during its life cycle from inception onward (Building and Construction Productivity Partnership, 2014).
CBI	Co-ordinated Building Information
CEN	European Committee for Standardisation (www.cen.eu)
CIL	Construction Information Limited.
Co-ordinated Building Information	A classification system designed by and for members of the construction industry to co-ordinate the five main information sources – drawings, specifications, quantities, technical and research information, and trade information and publications. CBI is based on the European CAWS (Common Arrangement of Work Sections) system and the ISO-sponsored Uniclass project.[1]
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (German Sustainable Building Council)
environmental product declaration	A voluntary declaration providing quantified environmental data using predetermined parameters and, where relevant, additional quantitative or qualitative environmental information. Also known as a Type III environmental declaration or Type III ecolabel.
EPD	environmental product declaration
GaBi	Proprietary LCA software.
GBCA	Green Building Council of Australia (www.gbca.org.au)
generic data	Data that depicts typical characteristics of products in a sector but is not necessarily representative of a specific named product in that sector. Data may be sourced or adapted from databases or derive from literature or other sources. Also known as secondary data.
GFA	gross floor area – usually measured in square metres (m^2)
Green Star	The NZGBC's voluntary environmental rating tool for buildings, which assesses a building at the design and as-built phases in the following areas: management, indoor environment quality, energy, water, transport, land use and ecology, emissions and innovation.
gross floor area	Sum of the area of all the floors of a building and includes mezzanines and balconies. The gross floor area is measured from the exterior faces of the exterior walls or from the centrelines of walls separating two uses within a building and includes all voids and unused parts of buildings (Ministry for the Environment, 2008).
HQE	Haute Qualité Environnementale – the green building standard in France
ISO	International Organisation for Standardisation (www.iso.org)
LCA	life cycle assessment
LCANZ	Life Cycle Association of New Zealand (www.lcanz.org.nz)

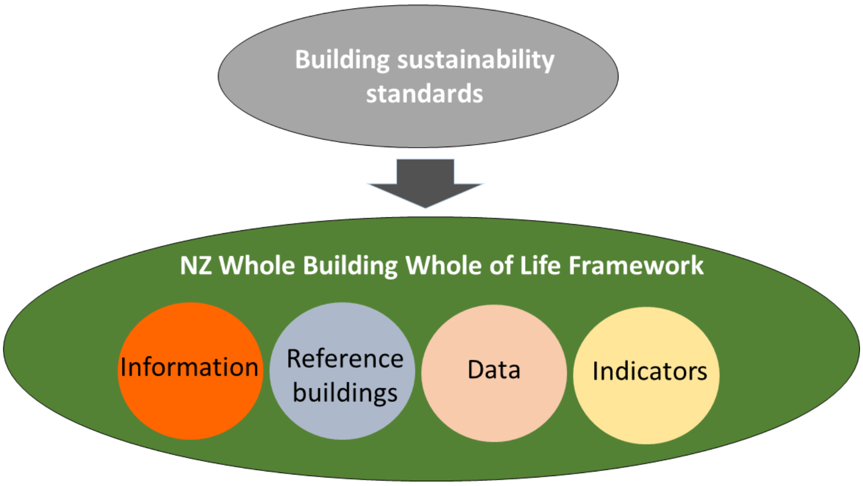
[1] Taken from the Masterspec website. For further information, visit www.masterspec.co.nz/industry-resource/cbi-classification-and-coding-overview-1130.htm.

LCAQuick – Office	Excel-based early design support tool developed by BRANZ to help architects and other professionals involved in design to better understand what LCA is, how to incorporate it into workflows and how to use LCA outputs to inform design decisions. Performs an evaluation of a design and compares it to one or more reference New Zealand office buildings.
LCI	life cycle inventory
LEED	Leadership in Energy and Environmental Design
life cycle assessment	Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (ISO, 2006).
life cycle inventory	Outcome of a life cycle inventory analysis that catalogues the flows across the system boundary and provides the starting point for life cycle impact assessment (ISO, 2006).
maintenance	The combination of all technical and associated administrative actions during the service life to retain a building or its parts in a state in which it can perform its required functions (ISO, 2011).
MBIE	Ministry of Business, Innovation and Employment (www.mbie.govt.nz)
MfE	Ministry for the Environment (www.mfe.govt.nz)
net floor area	The sum of the floors of a building measured from the exterior faces of the exterior walls or from the centrelines of walls separating two uses within a building and excludes all common areas such as hallways, and elevators, voids and unused parts of buildings (Ministry for the Environment, 2008).
net lettable area	See net floor area – usually measured in square metres (m^2).
New Zealand Life Cycle Management Centre	Based at Massey University and established to provide education, training and research to life cycle management professionals to meet increasing consumer demand for green metrics on products (www.lcm.org.nz).
NLA	net lettable area
NZGBC	New Zealand Green Building Council (www.nzgbc.org.nz)
NZIQS	New Zealand Institute of Quantity Surveyors (www.nziqs.co.nz)
reference service life	The service life of a product/component/assembly/system that is known to be expected under a particular set of in-use conditions and that may form the basis of estimating the service life under other in-use conditions (ISO, 2011).
replacement	The change of parts of an existing item to regain its functionality.
RS	research stream (within the New Zealand whole-building whole-of-life framework research)
scenario	A collection of assumptions and information concerning an expected sequence of possible future events (CEN, 2013).
service life	The period of time after installation during which a facility or its component parts meets or exceeds the performance requirements (ISO, 2011).
Simapro	Proprietary LCA software.
USGBC	United States Green Building Council
waste	A substance or object that the holder discards or intends or is required to discard (CEN, 2013).

1. Executive summary

BRANZ, with industry and research partners, has developed the New Zealand whole-building whole-of-life framework, which aims to provide information and resources to facilitate more consistent use of building life cycle assessment (LCA) in New Zealand. Initial focus has been on early design of new-build offices.

The framework is based on international building sustainability standards, with resources structured as shown below.



To facilitate comparability between LCAs of buildings, datasheets have been developed covering different parts of the building life cycle. The purpose of these datasheets is to help the development of consistent assumptions, inform development of scenarios (as defined in EN 15978 (CEN, 2011b)) and for filling data gaps when carrying out building LCA. While the focus of currently available datasheets is on application to new-build offices at early (concept and preliminary) design, the data may be useful for other building LCA studies. Datasheets have been developed covering the following:

- Weighted-average transport distances of construction products from the last manufacturer, fabricator or assembler to construction sites in Auckland, Wellington and Christchurch.
- Waste generated at construction sites (percentage by mass), percentages of waste going to reuse, recycling, energy recovery and landfill/cleanfill, plus information on likely recycling route.
- Required service life of an office building in the absence of building-specific information.
- Typical maintenance of building products during the building service life.
- Typical replacement of building products during the building service life.
- Default energy use data for energy modelling of commercial buildings, based on measurements in the Building Energy End-use Study (BEES)[2] and other sources.
- Benchmark water use in New Zealand commercial office buildings, based on Bint (2012).
- Typical and best-practice waste diversion rates (by mass) from landfill/cleanfill following building end of life. Reuse, recycling and recovery rates are provided as well as information on recycling or recovery route.

[2] www.branz.co.nz/BEES

This report provides supporting information about the methods used to develop the datasheets. As more and better data becomes available, it is intended that the datasheets will be updated. Stakeholders are invited to submit data and information to BRANZ for this purpose. The means to do this are set out in the BRANZ Study Report SR349 (Dowdell & Berg, 2016).

Datasheets provide the basis for modelling of reference buildings discussed further in BRANZ Study Report SR350 (Berg, Dowdell & Curtis, 2016) and are used to derive data for calculation of environmental impacts in *LCAQuick – Office*, a simple awareness-raising tool developed to help architects, designers and others involved in building design to better understand how to use LCA.

2. Introduction

2.1 Background

BRANZ commenced research into environmental profiling and whole-building whole-of-life assessment in 2010 to help answer questions raised by the construction industry about evaluation of environmental performance on the construction product and building scale. The initial research focused on how environmental product declarations (EPDs) underpinned by life cycle assessment (LCA) can provide a robust source of information for a more consistent evaluation of the environmental performance of construction products, which, in turn, can be incorporated in the assessment of New Zealand buildings across the life cycle.

Development of such a framework is important for the New Zealand construction industry because it:

- provides more of a level playing field for assessment, with a focus on environmental performance of buildings across the life cycle
- enables evaluation of the environmental performance of buildings according to their function
- provides a basis for comparing building designs in order to better understand the sources and scale of environmental impacts across the life of a building
- aligns with ongoing developments in building environmental assessment according to international standards
- provides a holistic assessment that does not focus on single issues or specific parts of the life cycle of a building, both of which risk problem shifting from one impact to another or one stage of the life cycle to another or one medium to another
- provides a basis for measuring continuous improvement through recognition of innovation based on reduced environmental impacts – this can be at the construction product level through to the building level
- facilitates a stronger connection between supply and demand for construction products – architects and designers that use LCA to evaluate their building designs rely on LCA-based data for construction products, which can be provided by manufacturers and importers. By making data about their products publicly available, manufacturers and importers can ensure data for their products is accurate and representative of current production as well as demonstrating a willingness for robustness and transparency
- with increasing use of quantitative design tools such as building information models (BIM) and energy models, opportunities for linking LCA-based data into the design process become quicker and easier. For example, provision of LCA-based indicators as metadata in freely-downloadable BIM objects of construction products provides opportunities for direct calculation of environmental impacts of building designs in BIM – this will increasingly facilitate more rapid assessment of building environmental performance during the design process.

In February 2013, BRANZ published BRANZ Study Report SR275 *Application of environmental profiling to whole building whole of life assessment – a plan for New Zealand* (Dowdell, 2013), which set out a vision and plan for how LCA and EPDs of construction products could be integrated with LCA-based building assessment in order to derive quantitative impacts for buildings across the life cycle. The plan was developed with existing New Zealand initiatives, structures and organisations in mind so as not to 'reinvent wheels' and to take account of developments in international standards concerning evaluation of the environmental performance of buildings.

Following a consultation with the New Zealand construction industry, the plan provided the basis for a 3-year Building Research Levy funded research programme to develop a New Zealand whole-building whole-of-life framework.

2.2 Organisation and focus of research streams

The framework aim is to provide information and resources to encourage and facilitate more consistent use of building LCA, with an initial focus on application to early design of new-build offices.

To achieve this aim, the research was divided into three research streams. A stakeholder group and industry interest groups were established in order to receive input to and feedback on the research from interested stakeholders.

The three research streams (RS) were organised as follows:

- *RS1 Establish LCA-based indicators to underpin the reporting basis of the framework:* This research completed in 2014 and resulted in publication of BRANZ Study Report SR293 (Dowdell, 2014). The report sets out current environmental indicators for reporting and environmental indicators highlighted for potential future incorporation into the framework. The report includes calculation methodologies and characterisation factors for use in calculating environmental impacts.
- *RS2 Develop calculated environmental impacts for a set of reference New Zealand office buildings, in order to provide an initial basis for comparison:* A simple matrix for categorising office buildings has been developed, and 10 New Zealand office buildings each with a gross floor area (GFA) of 1500 m^2 or more have been modelled according to materials used in the structure and thermal envelope and designed energy use according to location in Auckland, Wellington and Christchurch. This work has resulted in BRANZ Study Report SR350 (Berg, Dowdell & Curtis, 2016).
- *RS3 Develop default data for use when conducting building LCAs in the absence of specific data*. Excel datasheets have been developed that provide reference data for use in building LCAs of offices during early design. While the information has been developed for application to early-stage design, it may also be useful for other building LCA applications. These resources can be downloaded from the BRANZ website[3] and are supported by information in this report.

BRANZ has supported other research being conducted at the New Zealand Life Cycle Management Centre at Massey University as part of the framework. Outputs of this research will be made available on the BRANZ website as it is completed during 2016 and 2017. This research includes the following:

- An LCA-based evaluation of energy-efficient refurbishment in New Zealand offices to ascertain and recommend refurbishment options that yield the largest potential environmental gains. This research is due to complete in early 2017.
- An evaluation of the barriers faced by small to medium-sized enterprises (SMEs) that want to engage with LCA and what opportunities exist to help overcome these barriers. This research is due to complete in late 2016.

[3] www.branz.co.nz/buildingLCA

- Assessment of methods for calculating water scarcity impacts in New Zealand. The outputs of this research will be reported later in 2016.
- Development of an LCA-based model for New Zealand grid electricity generation and distribution in order to produce a life cycle inventory (LCI) for 1 kWh of low-voltage New Zealand grid electricity delivered to a building. The outputs of this work have been used in the framework.

Additionally, and with specific application to early design of office buildings, an awareness-raising tool called *LCAQuick – Office* has been developed by BRANZ. The aim of the tool is to provide a resource to help stakeholders involved in the early stages of building design to better understand LCA, in particular:

- what building LCA is and how to use it
- how to incorporate LCA into existing workflows
- what the outputs of LCA look like and how to use and interpret them
- how decisions taken at early design are likely to lead to environmental impacts during the building life, where these occur and how to reduce them
- how the environmental impacts of early designs compare to environmental impacts calculated for reference New Zealand office buildings.

LCAQuick – Office is available for download from the BRANZ website at www.branz.co.nz/buildingLCA and is accompanied by YouTube video tutorials (see the LCA playlist at www.youtube.com/user/BRANZmedia/playlists).

2.3 Key stakeholders

Key stakeholders to the framework, and how these stakeholders can interact with it, are mapped out in Section 3 of BRANZ Study Report SR349 (Dowdell & Berg, 2016). In brief, these stakeholders are as follows:

- Group 1: Manufacturers and importers of construction materials and products and their sector bodies/trade associations.
- Group 2: Architects, designers, structural engineers, specifiers, quantity surveyors and LCA practitioners involved in evaluating design of buildings using LCA.
- Group 3: Building rating tool providers (the New Zealand Green Building Council).

2.4 About this report

Figure 1 shows the stages of the building life cycle as set out in EN 15978 (CEN, 2011b). Each of these stages is subdivided into numbered modules.

Modules beyond the product stage may be informed by scenarios that are defined as a “collection of assumptions and information concerning an expected sequence of possible future events” in EN 15978 (CEN, 2011b). Section 8 of the standard sets out requirements for scenarios. Scenarios are useful because they provide transparency and also facilitate comparability between different LCAs that are based on the same scenario information.

As part of the development of resources for the framework, BRANZ has produced datasheets that provide information to support building LCA and scenario development. These datasheets are focused primarily on application to concept and preliminary design of new-build offices but may also be useful for other building and construction product level LCA applications.

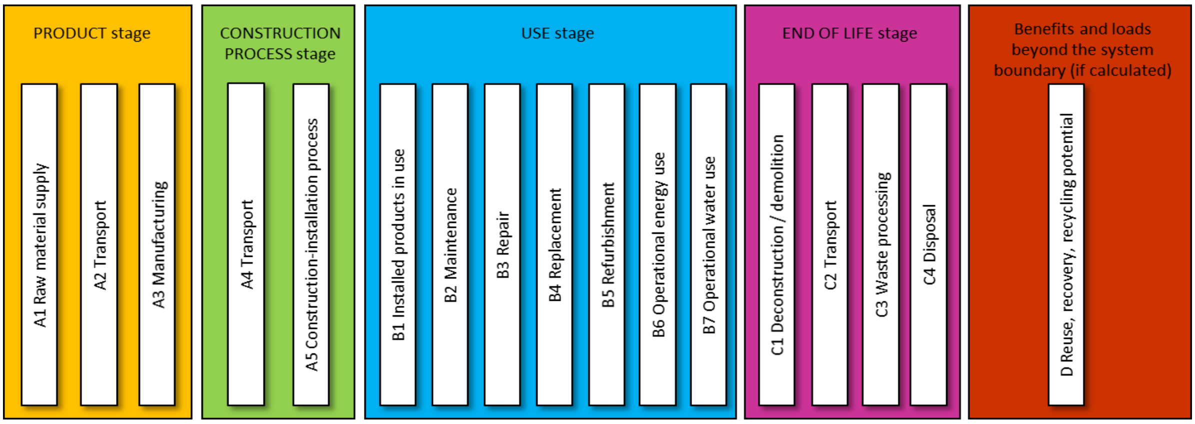


Figure 1. Stages of the building life cycle for use in the framework.

Datasheets are available on the BRANZ website[4] and may be freely downloaded. They are in Excel format. A summary of current datasheets in the framework is provided in Table 1.

Table 1. Summary of available datasheets to inform building LCA.

Module	Stage	Datasheet name[5]	Summary of content
A4 Transport	Construction process	Module A4 transport	Weighted average transport distances of construction products from the last manufacturer, fabricator or assembler to construction sites in Auckland, Wellington and Christchurch.
A5 Construction-installation	Construction process	Module A5 site waste	Waste generated at construction sites (percentage by mass), percentages of waste going to reuse, recycling, energy recovery and landfill/cleanfill plus information on likely recycling route.
Module B1–B7	Use	Module B1 to B7 required service life	Required service life of an office building in the absence of building-specific information.
Module B2	Use	Module B2 maintenance	Typical maintenance of products during the building service life.
Module B4	Use	Module B4 replacement	Typical replacement of products during the building service life.
Module B6	Use	Module B6 operational energy	Default energy use data for energy modelling of commercial buildings.
Module B7	Use	Module B7 water use	Benchmark water use in New Zealand commercial office buildings.
Module C1	End of life	Module C1 building end of life waste	Typical and best-practice waste diversion rates (by mass) from landfill/cleanfill following building end of life. Reuse, recycling and recovery rates are provided, as well as information on recycling or recovery route.

[4] www.branz.co.nz/buildingLCA
[5] All datasheet names have the prefix 'NZ WBWLF' and the suffix 'datasheet v1.xlsx', which are not included in this column.

This report provides information about how the datasheets have been derived and is organised as follows:

- Section 3: Module A4 transport to the construction site
- Section 4: Module A5 construction site waste
- Section 5: Modules B1 to B7 (use stage) office building required service life
- Section 6: Module B2 maintenance
- Section 7: Module B4 replacement
- Section 8: Module B6 operational energy
- Section 9: Module B7 water use
- Section 10: Module C1 building end of life waste

2.5 Use of datasheets

Datasheets have been developed for assessment of office buildings, but may also be useful when considering other types of buildings or other LCA applications. They are generic and therefore not product specific. This means that appropriateness for their use in LCA studies will need to be assessed by the user of the information. For example, during early design, there is less emphasis on specific manufacturers' products compared to later stages of design. This means that use of generic product data for assessing fundamentals of building design may be considered more reasonable in the absence of specific manufacturer data. Similarly, it may be considered unreasonable to rely on such data for an LCA that is specifically scoped to compare two or more products. The information provided in the datasheets is complementary to requirements and guidance provided in international standards summarised in Table 2.

Table 2. Summary of international and European standards for building LCA.

Level	ISO Standards (version at time of writing)	European Standards[6] (version at time of writing)
Framework standards	ISO 15392:2008 *Sustainability in building construction – General principles* ISO 21929-1:2011 *Sustainability in building construction – Sustainability indicators – Part 1: Framework for the development of indicators and a core set of indicators for buildings*	EN 15643-1:2010 *Sustainability of construction works. Sustainability assessment of buildings. General framework* EN 15643-2:2011 *Sustainability of construction works. Assessment of buildings. Framework for the assessment of environmental performance*
Building level standards	ISO 21931-1:2010 *Sustainability in building construction – Framework for methods of assessment of the environmental performance of construction works – Part 1: Buildings*	EN 15978:2011 *Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method*
Building product level standards	ISO 21930:2007 *Sustainability in building construction – Environmental declaration of building products*[7]	EN 15804:2012+A1:2013 *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products*

[6] Listed standards concern use of LCA. Other standards are EN 15643-3 (CEN, 2012a) which provides a framework for assessment of social performance of buildings and EN 15643-4 (CEN, 2012b) which provides a framework for assessment of economic performance of buildings.
[7] At the time of writing, this standard is being updated.

Datasheets are not provided for the following modules:

- *Modules A1 to A3 (manufacture of construction products):* These modules should, ideally, be represented with data from environmental product declarations (EPDs) relevant to New Zealand or LCA-based cradle-to-gate data. BRANZ, with other LCANZ and ALCAS members, worked towards and supported the establishment of the Australasian EPD® Programme to provide manufacturers with the opportunity to declare the environmental impacts of their products, based on LCA. For options about providing LCA-based data for products for use in building LCA, see BRANZ Study Report SR349 (Dowdell & Berg, 2016).
- *Module B1 (installed products in use):* This should, ideally, be based on measurement. Work is being undertaken internationally to develop consistent testing methods. As a result, more data covering module B1 is likely to be available in EPDs in the future.
- *Module B3 (repair):* Repair may be necessary where the frequency and/or type of maintenance that is carried out is not in accordance with manufacturers' instructions or random and/or accidental events may occur causing damage to parts of a building, such as storm damage. An assumption is that maintenance in the module B2 datasheet is carried out and therefore repair is not required during the service life of the product. Damage due to random events is not currently considered.
- *Module B5 (refurbishment):* Refurbishment of New Zealand office buildings is the subject of doctoral research being conducted at the New Zealand Life Cycle Management Centre at Massey University with a BRANZ scholarship. The outputs of this research will be separately reported on completion of the research (due in 2017).

2.6 Future updates

BRANZ would like to update datasheets in the future with availability of more and better data and information and/or as international standards develop. BRANZ welcomes submission of data and information from stakeholders for these updates. The process for doing this is set out in BRANZ Study Report SR349 (Dowdell & Berg, 2016).

Future updates to datasheets will be available on the BRANZ website.[8]

[8] www.branz.co.nz/buildingLCA

3. Module A4 transport to the construction site

Module A4 covers transport of construction products to the construction site. Data for this module are provided in the accompanying Excel spreadsheet entitled *NZ WBWLF – Module A4 transport datasheet [version number]*, which can be freely downloaded from the BRANZ website at www.branz.co.nz/buildingLCA. The datasheet provides generic transport distances for building products to construction sites in Auckland, Christchurch and Wellington. Analysis[9] is provided for these cities because they are most likely to have large office developments.

The transport datasheet provides distances for the main products used, according to 4-digit (work section) CBI codes[10] most likely to be associated with office buildings. The CBI has been used under licence granted by Construction Information Limited (CIL).

Generic distances provided in the transport datasheet are derived based on the following:

- The defined starting point for the journey is the gate at the boundary of the last manufacturing, fabrication or assembly operation, prior to delivery to the construction site. Distances are assumed to be direct, meaning no allowance is made for interim transportation to storage facilities or construction product merchants, which may add to distances.
- The defined end point for the journey is the construction site in a central business district (CBD) location in Auckland, Wellington or Christchurch.
- Distances are presented as one way only. Return truck journeys should be considered if empty or part loaded if data used permit.
- For overseas products, transport by truck in the country of origin is not included – it is an assumption that manufacture occurs close to a port of origin.
- Transport between suppliers and the last manufacturing, fabrication or assembly stage is covered in module A2. Therefore, this transport is not included in the transport datasheet. Typically, data for module A2 transport may be provided or incorporated into results published in EPDs or life cycle inventories (LCIs). It is important to establish what the boundaries are of data reported in EPDs or provided in LCIs to ensure there are no significant gaps or double counting when modelling transport. For example, in *4311 Profiled metal sheet roofing* in the transport datasheet, the gate is defined as the metal roofing manufacturer's facilities, largely based in New Zealand. Care therefore needs to be taken to ensure that data for steel manufacture covers transport to the metal roofing manufacturer.

3.1 Method for determining default transport distances

The transport datasheet is provided with a 'How to use' section (yellow tab). BRANZ recommends that this is read before data from the datasheet is used.

It is set up to provide default transport distances by ship, rail and road from the gate of the last manufacturing, fabrication or assembly stage to the construction site. In

[9] The analysis was carried out in 2014/15 and is based on information available at that time.
[10] Co-ordinated Building Information (CBI) is a construction classification system used in New Zealand, developed by CIL. For more information, please refer to www.masterspec.co.nz/industry-resource/cbi-classification-and-coding-overview-1130.htm

practice, no information or data was found to support transport by rail. Transport by air is not currently supported but can be added in a future update if this is a mode of transport that is used for particular products.

Manufacture, fabrication or assembly of products used on construction sites may take place in New Zealand or in other countries. In most product categories, there are a number of different suppliers although occasionally only one supplier may be found or listed. Where this is the case, provided transport distances will be skewed based on the location(s) of this supplier.

Ideally, generic transport distances should reflect the range of all locations of sites supplying products to the New Zealand market currently. It should, ideally, also take into account the market shares of products in New Zealand.

Due to the number of products potentially used in office buildings, a method needed to be devised to develop generic transport distances. This is set out below:

- Step 1: List suppliers by CBI work section.
- Step 2: Identify 'gate' location per supplier.
- Step 3: Assess distance between supplier gate and construction site.
- Step 4: Weight supplier contribution by market share.

3.1.1 Step 1: List suppliers by CBI work section

The transport spreadsheet is organised according to the CBI hierarchy of 1-digit (class), 2-digit (group) and 4-digit (work section) codes, with descriptions. Next to each 4-digit (work section) code is a listing of specific products that may be delivered or 'whole system' when delivered as a complete or near complete system. For example, in *2311 Cast in place concrete piling*, the main materials *Concrete (in situ)* and *Steel (reinforcing or mesh)* are listed as they are supplied separately and therefore have different journeys. However, in *4211 Proprietary curtain walling*, 'whole system' is listed as the curtain wall system is transported as one system and therefore there is one associated journey.

In order to ascertain suppliers of products, www.miproducts.co.nz was used, since this contains product listings by 4-digit CBI code. This was supplemented with:

- information from member directories of industry associations such as www.nzrmca.org.nz, www.precastnz.org.nz, www.scnz.org, www.wanz.org.nz, www.wpma.org.nz and www.nzwood.co.nz
- published BRANZ Appraisals
- BRANZ knowledge and judgement.

3.1.2 Step 2: Identify 'gate' location by supplier

Two methods were used to identify manufacturer gates, as defined in Section 3:

- Analysis of publicly available information on suppliers and manufacturers from their websites. Most supplier websites were identified by entering their name in the Google search engine.
- BRANZ knowledge of suppliers.

For manufacturing or assembly operations outside of New Zealand and Australia, the country of origin was sought. For New Zealand and Australia, the city or region was sought.

In the absence of any information about location of manufacture or assembly, a prudent assumption was made that the product is imported from Europe – the longest transport journey.

Distance data is based on supplier listings from Section 3.1.1. This means distances for a named material or product such as *Composite panel* may vary according to the class and group within the CBI in which it is used. It is therefore important to consider how the product will be used in the building (using CBI 4-digit codes) as well as the product name. For example, transport of *Composite panel* in *3831 Interior timber work* to Auckland shows a ship distance of 2,500 km and a road distance of 50 km. However, *Composite panel* transport to Auckland in *4333 Metal faced insulating panel flat sheet roofing* has a ship distance of 1,000 km and a road distance of 50 km.

3.1.3 Step 3: Assess distance between supplier gate and construction site

A mode-distance assessment model was developed as the basis for assigning transport journeys to products. This assessment model is presented in Figure 2.

Module A4: Mode-distance assesment model for base data of products

	Distance Range			Transport Mode Coding and Range			
Distance Category Name	Minimum	Maximum	Default Category Distance	ship	train	road	gate location description
urban 1	0	10	10			V0	within metropolitan urban limit
urban 2	10	25	25			V1	within metropolitan urban limit
regional 1	25	50	50		T2	V2	near metropolitan urban limit
regional 2	50	100	100	S3	T3	V3	Auckland region outside metropolitan urban limit
interregional 1	100	250	250	S4	T4	V4	Same Island
interregional 2	250	500	500	S5	T5	V5	Same Island
interregional 3	500	1000	1000	S6	T6	V6	Other Island
interregional 4	1000	2500	2500	S7	T7	V7	Other Island
international 1	2500	5000	5000	S8	T8	V8	East Coast Australia, Pacific Islands
international 2	5000	10000	10000	S9			West Coast Australia, South-East Asia
international 3	10000	25000	25000	S10			Rest of the World

Figure 2. Mode-distance assessment model used in module A4.

The model defines two urban distances, two regional distances, four inter-regional distances and three international distances. Each has a minimum and maximum threshold distance and a default distance, which is set as the maximum distance in the threshold range. For example, the threshold distance for the category *urban 2* is 10–25 km, with a default of 25 km. Similarly, the threshold distance for *international 3* is 10,000–25,000 km, with a default distance of 25,000 km. This means that, when a journey is assigned to a range, the default distance is automatically selected. For example, a product imported from Perth, Australia, would be allocated an *international 2* journey (which covers shipping from Western Australia and Southeast Asia), which covers distances between 5,000 and 10,000 km. In this case, 10,000 km would be automatically selected as the maximum threshold distance in the distance range.

For each distance category, one, two or three transport modes may be available for the journey. These modes are defined as 'ship', 'train' and 'road'. Looking at Figure 2, only road transport (V1) is available for an *urban 2* journey, and only a ship journey (S10) is available for an *international 3* journey. In other cases, such as an *inter-regional 3* journey, the mode may be ship (S6), train (T6) or road (V6).

Based on identification of the supplier's gate in step 2 and the location of the construction site (in Auckland, Christchurch or Wellington), journeys are built up using the mode-distance assessment model. Journeys by mode are assigned to each supplier. Assignment of a journey to a range means the default distance for the range is taken as the distance travelled.

This categorisation facilitates the rapid evaluation of transport distances from numerous suppliers. This process may overestimate transport distances. For example, continuing with the Perth example above, the real shipping distance to New Zealand is around 5,500 km, but since this falls within the *international 2* category, a default shipping distance of 10,000 km is allocated.

Thus, use of the mode-distance assessment model simplifies real transport journeys into 11 categories and, in so doing, errs on the side of prudence with respect to allocated journey distances.

All imported products are assigned a shipping contribution in the categories S8, S9 and S10 depending on the country of origin. Imported products are assumed to arrive at the port closest to the construction site – Auckland, Christchurch or Wellington. The road contribution associated with imported products is assigned to category V3 to reflect the distance from the New Zealand port to a local distributor and on to the construction site. Road transport in other countries has not been taken into account.

Where data was available on modes used by suppliers, these have been included, although, in practice, little information was found. In the absence of specific data on mode of transport, movement by truck is assumed. Thus, for a product made near Auckland that is used on a Christchurch build, it is assumed that the product is transported by truck (with a ferry journey from the North to South Island, assigned as an S3 journey) unless specific information stating alternative modes (rail or coastal shipping) could be found.

3.1.4 Step 4: Weight supplier contribution by market share

Distance data can be weighted according to market share of suppliers to provide a weighted average distance for each mode (ship, train, road). In practice, little information was found concerning market share of different suppliers. In these cases, equal market share amongst identified suppliers was assumed.

Products for which market share information was obtained, which has been incorporated into the transport spreadsheet, are as follows:

- Steel reinforcement, for which Pacific Steel has a market share of 85%. The remaining 15% of market share is divided equally between other suppliers. With the acquisition of Pacific Steel by New Zealand Steel, we assume no change to these market shares and that transport distances are the same.
- Plasterboard, for which Winstone Wallboards has a market share of 94%. The remaining 6% of market share is divided equally between other suppliers.

4. Module A5 construction site waste

Module A5 covers all construction-related activities on construction sites and associated offsite processes that may result from construction activities. Examples are:

- preparing the site for construction, including excavation, levelling, earthworks and soil stabilisation, using heavy plant and equipment
- moving products and materials into position, for example, through use of tower cranes, which may be electric or diesel powered
- adapting materials, for example, through cutting or grinding, and fixing materials to other materials using power tools
- generation of wastes either through wastage from cutting materials to size or through excess amounts being brought to site – these wastes may be subsequently transported to landfill or may be transported for reuse, recycling or recovery

The manufacturing impacts of materials that become waste in module A5 are also allocated here. Thus, modules A1 to A3 reflect the manufacturing impacts of materials that are used in the building. The manufacturing impacts of any extra material that becomes waste during construction is reflected in module A5.

A datasheet has been developed covering generation of waste on construction sites and is entitled *NZ WBWLF – Module A5 site waste datasheet [version number]*. It is in an Excel format and can be downloaded from the BRANZ website at www.branz.co.nz/buildingLCA. The data provided in the site waste datasheet may be applied in the absence of specific data.

Waste rates in the site waste datasheet are provided as a percentage figure by mass above the mass of the material used in the building. For example, the waste rate for in-situ concrete is provided as 4%. This is interpreted as meaning that 4% more in-situ concrete is delivered to the construction site than is used in the building. Thus, if the in-situ concrete in a building comprises 100%, the amount of concrete transported to the construction site to achieve this is 104%.

In this example, the transport impact of in-situ concrete to the construction site should therefore be based on transporting 104% of the material, which is calculated in module A4. The manufacture of the 4% of in-situ concrete that ends up as waste is considered in module A5. The transport, recycling and disposal of the 4% waste in-situ concrete produced at the construction site is additionally considered in module A5.

4.1 Sources of data for construction site waste rates

In practice, waste management on commercial construction sites varies according to waste management plans[11] and the processes used by the various trades that operate on a site over its duration (Dolan, Lampo & Dearborn, 1999). Opportunities for waste minimisation on construction sites is dependent on choices made by all stakeholders during the construction process. Data provided in the site waste datasheet has been derived or estimated based on several sources, taking into account where possible (in order of importance):

- New Zealand practices
- commercial construction

[11] www.branz.co.nz/REBRI

- recent construction (2 years from 2014/15 when the analysis was carried out).

Where this data was not found, data from wider sources has been used, for example, international data or data derived from New Zealand residential construction sites. Where this data is used, the assumption is that New Zealand commercial construction site waste rates are the same as those internationally or on New Zealand residential construction sites. Literature information sources are provided in the site waste datasheet.

In addition to sourcing literature information, Hawkins Construction provided estimates of waste rates and other data (Appendix A), based on experience of operating commercial construction sites.

Additional notes are provided in the site waste datasheet that provide further information about waste rates and, in some cases, different values where these have been found in alternative sources.

4.1.1 Waste rate assumptions

Where no data was found for products, assumptions have been made based on available data for similar products. In these cases, the same assumptions are applied. For example, all types of blocks and bricks have a 5% waste rate, of which 90% of the waste is assumed to be reused with the remainder going to landfill.

Many factors affect actual waste rates, including incorrect plans or site measurements and differing site practices from different labourers and equipment.[12] Any waste that may be created because of errors in sizing or ordering are assumed to be rare and ignored.

The site waste datasheet provides generic values for application in a building level assessment when the impact of errors in waste rates is likely to be small in the context of impacts from the life cycle of a building. Where LCAs may be carried out for other applications, for example, evaluating different products for environmental performance, specific waste rates may be required if significant to results.

Stakeholders in the construction industry are invited to contribute data concerning waste rates for products generated on construction sites. The process for doing this is set out in the BRANZ Study Report SR349 (Dowdell & Berg, 2016). It is expected that the data in the site waste datasheet will be periodically reviewed and updated as more data becomes available.

[12] www.branz.co.nz/REBRI

5. Modules B1 to B7 (use stage) office building required service life

The datasheet *NZ WBWLF – Module B1 to B7 required service life datasheet [version number]* provides a service life for a New Zealand office building of 60 years, in the absence of a client brief requiring a stated alternative service life for a new office building.

5.1 Literature review findings

No New Zealand-specific journal papers were found that addressed the issue of office building life. However, clause B2.3.1(a) of the New Zealand Building Code sets an expectation that the life of a building will not be less than 50 years unless a shorter specified intended life is stated. During this period, building elements must continue to satisfy the performance requirements of the New Zealand Building Code.

In September 2013, the issue was discussed at a project workshop hosted by BRANZ with construction industry stakeholders at which findings from overseas studies, summarised below, were presented. A view taken at the workshop was that 60 years is reasonable, given that 50 years is a minimum durability requirement for structures of buildings and that buildings are inherently designed with greater resilience than this minimum. Since the workshop, the GBCA and the NZGBC have adopted a 60-year building life in their Green Star building environmental rating tools.

Overseas, Komatsu and Endo (2000) reported the findings of their work to assess the lifetime of Japanese buildings using a periodical remaining rate estimation method. Using this approach, the expected average lifetime of a building is defined when 50% of the original buildings of a particular age remain. In this case, a building lifetime of 50 years means that half of the buildings of that age remain after 50 years and half have already been demolished. The analysis was only carried out for residential constructions, however.

In Japan, the Ministry of Finance defines a typical building service life for calculating depreciation for income tax and business tax purposes. Komatsu (2013) analysed building lifetimes using registry information collected for levying property taxes. The results of his analysis in comparison with legal definitions of service life are summarised in Table 3.

Table 3. Summary of legal and analysed building lifespans in Japan.

Building type	Legal lifespan definition (years)	Analysed lifespan (years)
Wooden house	22	64
Reinforced concrete office	50	56

Similarly, in New Zealand, typical accounting convention is to depreciate buildings at a 2% flat rate so that the building is fully depreciated after 50 years.

Komatsu found that actual lifespans were different from legally defined building service lives in Japan. A finding of the work is that building lifespans tend to be considered on the basis of the durability of the building materials used but that how well these materials are used also appears to have a significant impact.

O’Connor (2004) suggests that there is no significant relationship between the structural system and actual useful life of a building, with reasons for demolition being primarily related to:

- changing land values
- lack of suitability of the building for current needs
- lack of maintenance of various non-structural components.

These findings were based on results of a demolition survey of 227 buildings in Minneapolis/St Paul, representing 75% of all demolitions during the study period. Like Komatsu, O’Connor challenges the view that use of what would traditionally be considered as more durable structural materials leads to longer building service lives and found that the majority of demolished steel and concrete buildings in the study were less than 50 years old. There appears, therefore, to be a disconnect between how long a building can last and how long it is actually kept in service.

Similarly, O’Connor summarises findings from a number of North American studies that aimed at determining average building ages:

- The US Department of Energy had 10,707 buildings in its portfolio in 2002, with an average age of 31 years.
- The average age of 78,000 public schools in the USA in 1998 was 42 years, with most schools being abandoned by the age of 60.
- Based on US Census Bureau records, the average age of 119,117,000 residential buildings was 32 years.
- Statistics Canada reported that the average age of non-residential buildings in Canada in 2003 was less than 18 years.

Van Nunen and Mooiman (2011) highlight how the life span applied to a building and service lives of its construction products can have a significant influence on the outcome of LCAs. Service life of construction products is discussed further in Section 7.

6. Module B2 maintenance

Module B2 covers normal maintenance activities required to ensure a constructed system in a building continues to provide an expected level of functionality across its expected service life. It does not include unplanned activities such as fixing storm-damaged items, which would typically be considered in module B3 repair.

Maintenance information is provided in the Excel spreadsheet called *NZ WBWLF – Module B2 maintenance datasheet [version number]*, which can be downloaded from the BRANZ website at www.branz.co.nz/buildingLCA. This is organised by 4-digit (work section) CBI code.

Figure 3 provides an extract featuring the structure of the datasheet. Next to each work section (4-digit CBI code and name) is a list of the main products, followed by a description of the maintenance activity, which is also quantified under 'Activity (quantity)'.

These quantities are provided in units that facilitate calculation of environmental impacts as a result of material and energy inputs from maintenance activities. Examples include volume of water use per area of curtain wall or façade for washing (L/m^2) and the volume of paint used to cover an area of external wall (L/m^2), taking into account the number of coats typically applied.

The frequency of an activity is provided in the 'Activity frequency' column. This summarises the periodicity of the activity in years. For example, a 1 means the activity is carried out yearly, and a 5 means the activity is carried out every 5 years.

Maintenance information was compiled from local and international literature and product information. BRANZ materials knowledge has also been used to derive the data.

Not all CBI codes have maintenance activities associated with them. Some building components, such as steel reinforcing within concrete, are inaccessible. Other components may be inherently unmaintainable, such as polycarbonate corrugated roofing, and are simply replaced at their end of life. In some instances, there is a lack of information regarding maintenance. Many CBI codes cover building elements that may be constructed from a range of products, for example, *4232 Metal and metal faced flat sheet cladding* may comprise a range of materials such as steel, stainless steel, aluminium, copper and zinc, which have very different maintenance requirements. Specialist or proprietary components and components unlikely to be used within New Zealand were not included.

Maintenance requirements and frequency are affected by external factors such as environmental conditions and how the component is used. Values given in the spreadsheet are a best approximation. Sources are referenced within the spreadsheet and have been generalised where it is reasonable to do so.

Most building elements comprise a number of different products. In these cases, the materials considered to be relevant for regular maintenance purposes have been identified and the maintenance activity set out adjacent to the material. For example, maintenance on CBI code *4511 Timber windows, doors and roof lights* concerns washing of the glazing and timber frame as well as reapplication of the protective coating or decorative finish to the timber frame.

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Module B2			Maintenance by CBI Code Datasheet							
CBI Code	Work Section	Materials/products needing maintenance	Maintenance - description	Maintenance - quantity			Frequency (years)	Source(s)	Additional Notes	Exceptions
				Item	Quantity	Units				
4331	Fibre cement flat sheet decking	Fibre cement sheets	Wash	Water	1	L/m2	1	5	If accessible.	CBI code 4331 (flat sheet decking) for which washing required every 15 years (Source: 25).
		Composite panel	See Additional Notes column	-	-	-	-	-	Proprietary systems make provision of generic data difficult. Recommendation is to seek system-specific information from the manufacturer or supplier. Assumption is that the panels require washing at 1L of water per m2 of panel.	-
		Protective coating/decorative finish (timber2)	Reapply (two coats)	Protective coating/decorative finish	0.17	L/m2	8	1, 13	If previously applied on the construction site and still accessible. Based on two coats of acrylic paint.	-
4333	Metal faced insulating panel flat sheet roofing	Composite panel	See Additional Notes column	-	-	-	-	-	Proprietary systems make provision of generic data difficult. Recommendation is to seek system-specific information from the manufacturer or supplier. Assumption is that the panels require washing at 1L of water per m2 of panel.	-
		Protective coating/decorative finish (timber2)	Reapply (two coats)	Protective coating/decorative finish	0.17	L/m2	8	1, 13	If previously applied on the construction site and still accessible. Based on two coats of acrylic paint.	-
4336	Solar energy-collecting flat panel roof	Solar panel	*NO DATA*							
		Protective coating/decorative finish (timber2)	Reapply (two coats)	Protective coating/decorative finish	0.17	L/m2	8	1, 13	If previously applied on the construction site and still accessible. Based on two coats of acrylic paint.	-
4337	Plywood roofing and decking	Plywood	No significant maintenance required							
4351	Timber shingle and shake roofing and wall-hanging	Timber (solid)	Wash	Water	1	L/m2	1	10	If accessible.	-
		Timber (engineered panels) eg. MDF, OSB, particleboard	Wash	Water	1	L/m2	1	10	If accessible.	-
4354	Pressed metal shingle, roofing and wall-hanging	Steel (sheet)	Wash	Water	1	L/m2	1	5	If accessible	-
4355	Pressed copper shingle roofing and wall-hanging	Copper	Wash	Water	1	L/m2	1	5	If accessible.	-
4361	Fully supported flat steel sheet roofing	Steel (sheet)	Wash	Water	1	L/m2	1	5	If accessible	-
		Protective coating/decorative finish (steel)	Reapply (one coat)	Protective coating/decorative finish	0.1	L/m2	8	2	If accessible. Applies to coatings added on construction site from installation and factory applied coatings from year 25. Due to fading over time, assume that all accessible areas would be recoated due to difficulties in colour matching. Coatings may be polyester, epoxy or polyurethane based. Application rates can vary with different chemistries.	-
4362	Fully supported flat stainless steel sheet roofing	Stainless steel	Wash	Water	1	L/m2	1	5	If accessible.	CBI code 35 (structural stainless steel) which is not washed for accessibility reasons and 4311 (roofing) as not necessary.
4363	Fully supported flat aluminium sheet roofing	Aluminium	Wash	Water	1	L/m2	1	5	If accessible.	CBI code 3612 (structure) which is not washed for accessibility reasons.
		Protective coating/decorative finish (aluminium)	Reapply (two coats)	Protective coating/decorative finish	0.17	L/m2	8	13	If accessible. Applies to coatings added on construction site from installation and factory applied powder coatings from year 35. Due to fading over time, assume that all accessible areas would be recoated due to difficulties in colour matching.	Does not apply to anodised aluminium.
4364	Fully supported flat cooper and bronze sheeting, used as a covering to flat and sloping roofs	Copper	Wash	Water	1	L/m2	1	5	If accessible.	-
4365	Fully supported flat zinc sheet roofing	Zinc	Wash	Water	1	L/m2	1	5	If accessible	-

Figure 3. Extract illustrating the maintenance datasheet.

The maintenance tasks most recommended by manufacturers and in the literature were cleaning, recoating (painting or staining) and replacing sections of sealant or grouting. Maintenance of protective coatings on the building enclosure ensures protection of the underlying components. This is essential to prevent deterioration and retain the functionality of the larger system.

Washing generally has a low material input. However, it should be performed relatively often. The labour costs and inputs may outweigh the material inputs involved. Lower maintenance materials may need less frequent maintenance. For example, self-cleaning glass only needs to be cleaned twice a year, compared with four times a year for standard glass, reducing both the material input (water) and the labour input. Lower-maintenance alternatives, such as self-cleaning glass, are not separately considered in the datasheet.

Recoating is performed less frequently than washing. However, it has higher maintenance and labour inputs. Some products, such as galvanised roofing, can be maintained by minor patch repairs and recoating. These activities can become more frequent near the end of the service life of the roofing and eventually become uneconomical when compared to replacement.

At some point in time, maintenance activities will cease to be a viable option, and replacement is required. The point at which this should occur can be difficult to determine. For example, an old roof that becomes embrittled with age can be broken when walked on during repainting, making continued maintenance untenable.

In reality, maintenance on a building may not be carried out at the intervals specified by manufacturers or using the method that they specify. This may result in deterioration and potentially failure of the product earlier than if appropriate periodic maintenance had been carried out.

7. Module B4 replacement

Module B4 covers typical replacement frequencies of whole or sizeable parts of constructed systems. Replacement of a constructed system is required from a technical standpoint when it no longer delivers the level of functionality required and has therefore reached the end of its service life. Constructed systems may be replaced earlier for non-technical reasons, for example, when they no longer meet aesthetics needs or wants. While this may be considered as another part of functionality, it is not considered here.

Replacement data is located in the *NZ WBWLF – Module B4 replacement datasheet [version number]* Excel spreadsheet, which can be freely downloaded from the BRANZ website at www.branz.co.nz/buildingLCA. Figure 4 provides an extract showing how data is arranged by 4-digit (work section) CBI code. As with other datasheets, the main products for each 4-digit CBI code are listed, although replacement data primarily relates to the whole constructed system.

Estimated service life data is given as typical in years, with minimum and maximum values where available. For example, *4421 Bitumen based sheet roofing* may typically be expected to last 22 years before needing replacement, with a minimum of 20 years and a maximum of 25 years.

Replacement intervals listed for a constructed system are independent of the expected life of supporting components and the expected life of the building as a whole. For example, a concrete component with a typical life of 100 years will exceed the typical office building service life of 60 years and has its estimated service life listed as 100 years.

Replacement information has been compiled from New Zealand and international references and product literature. Replacement information was assessed against BRANZ materials knowledge to provide final figures.

Some building elements may vary with respect to specific materials used and therefore service life. For example, *4311 Profiled metal sheet roofing* may be made using steel, stainless steel, aluminium, copper, and zinc. Some materials may require maintenance in order to achieve the estimated service life (see Section 6), while others may not need any maintenance. Where possible, the effect of different materials has been factored into service life values to give a best approximation.

Sources are referenced within the datasheet and have been generalised where it is reasonable to do so. Replacement required because of random events such as accidents or natural events (storms, earthquakes) or other circumstances inducing premature failure is not currently considered.

Module B4			Constructed Systems/Materials Replacement Scenarios by CBI Code				
CBI Code	Element	Main materials/products potentially present in combination/as alternatives	Estimated Service Life			Source(s)	Additional Notes
			Typical	Min	Max		
4231	Fibre cement flat sheet cladding	Fibre cement sheets Building wrap Insulation Protective coating/decorative finish	50	40	60	10	
4232	Metal and metal faced flat sheet cladding	Aluminium Composite panel Insulation Building wrap Protective coating/decorative finish	60			13	Stainless steel, copper and zinc have an expected life of 60 years. Coated steel that is maintained has an expected life of 50 years.
4234	Plastics and plastics-faced flat or shaped sheet cladding	Plastics Composite panel Insulation Building wrap Protective coating/decorative finish	60			13	
4241	Metal profiled sheet cladding	Aluminium Steel (sheet) Composite panel Plastics Insulation Building wrap Protective coating/decorative finish	60			13	Stainless steel, copper and zinc have the same expected life. Coated steel that is maintained has an expected life of 50 years.

Figure 4. Extract illustrating the replacement datasheet.

8. Module B6 operational energy

Information to help with energy modelling of office buildings is provided in the *NZ WBWLF – Module B6 operational energy [version number]* datasheet ('energy datasheet'), which can be downloaded from the BRANZ website at www.branz.co.nz/buildingLCA.

Information provided in the datasheet is presented for:

- occupancy by building activity
- internal energy end uses
- internal heat gains
- zone airflow and ventilation
- thermostat setpoint and HVAC
- building materials
- air gaps
- glazing and frame materials.

Information is drawn from several sources, which are cited in the 'References' section of the datasheet. BRANZ recommends using defaults in the datasheet obtained from BEES[13] (unless energy modelling is being carried out for the purposes of a Green Star rating), as this data is derived from measured energy use in New Zealand commercial buildings during a 6-year study.

Other data (not obtained from BEES) presented in the datasheet is from standards and guidance and may vary, depending on the source and underlying basis and assumptions. In cases like this where alternative values may be used, the data used for modelling reference buildings in *LCAQuick – Office* is provided in the datasheet in black, with other (alternative) data shown in grey. It is recommended to use the default values in black in the datasheet for energy modelling of building designs in order to maintain comparability with the reference buildings, unless there are underlying reasons to do with the client's requirements and design that mean this is not reasonable.

Section 8.2 provides further guidance on the approach to energy modelling so that it is aligned with EN 15978 (CEN, 2011b).

8.1 A note about energy assessment for Green Star

Some default values required for a Green Star assessment are different to defaults in the energy datasheet. Main areas of difference between BEES and Green Star defaults are:

- the various building operating schedules
- building integrated vertical transport (elevators/escalators)
- tenant small power
- office occupancy density
- outdoor air supply
- infiltration rates
- thermostat set points.

[13] www.branz.co.nz/BEES

Reference office buildings available in *LCAQuick - Office*, modelled using BEES defaults, may not be suitable as a basis for comparison to obtain recognition in the building LCA Innovation Challenge in Green Star.

However, users of *LCAQuick – Office* may be able to use the tool to calculate environmental impacts of their own defined reference building against which they can make a comparison of their design. In this case, energy modelling may be carried out using Green Star defaults and *LCAQuick – Office* can produce associated environmental impacts. Use of *LCAQuick – Office* for this purpose and using this approach should be discussed with NZGBC.

8.2 Energy modelling according to EN 15978

8.2.1 Energy demand

In EN 15978 (CEN, 2011b), operational energy demand is categorised into three groups:

- Building related/building integrated technical systems included in EN 15603 (CEN, 2008).
- Building related/building integrated technical systems not included in EN 15603 (CEN, 2008).
- Non-building-related energy.

This categorisation is based on ensuring EN 15978 (CEN, 2011b) aligns with other European standards such as *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings*, specifically EN 15603 (CEN, 2008).

Figure 5 illustrates the three categories as presented in EN 15978 (CEN, 2011b). Categories 1 and 2, the building-related energy end uses, are mandatory energy end uses required to be included in a building LCA according to the standard. Reporting of the third category, non-building-related energy, which includes all energy end uses that are tenant dependent, is optional and, if included, must be documented, reported and communicated separately.

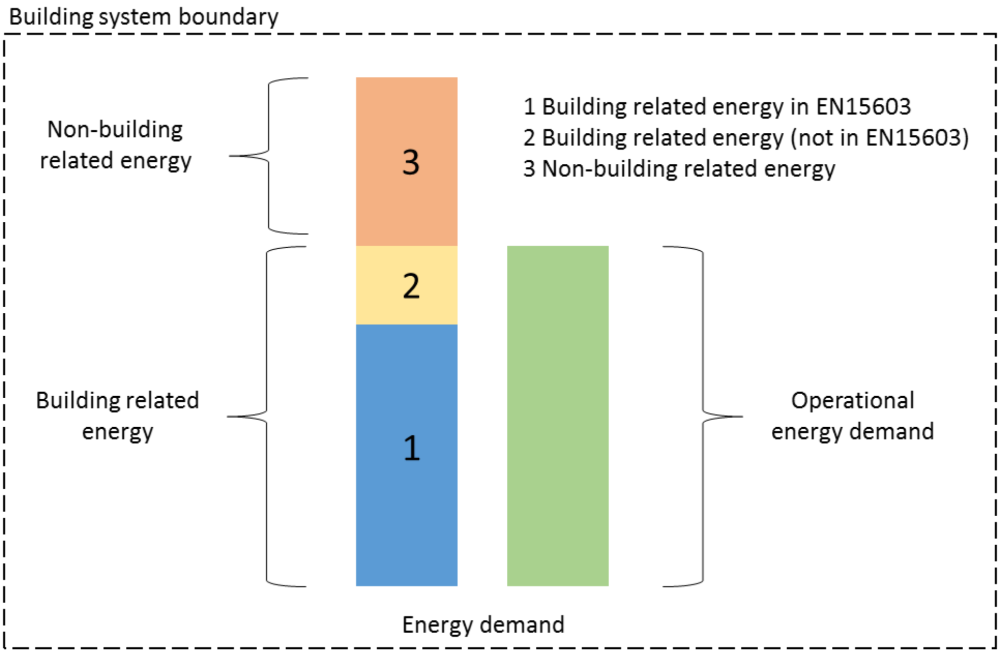

Figure 5. Operational energy categories (based on EN 15978 (CEN, 2011b)).

Table 4 presents a more detailed breakdown of energy end uses and their allocation within EN 15978 (CEN, 2011b).

Table 4. Energy end uses included in categories 1, 2 and 3.

EN 15978 required	**Category 1: Building-related/building integrated technical systems consuming energy included in EN 15603 (CEN, 2008).** • Heating • Domestic hot water supply • Air conditioning (cooling and humidification/dehumidification) • Ventilation • Lighting • Auxiliary energy used for pumps, control and automation
	Category 2: Building-related/building-integrated technical systems consuming energy not included in EN 15603 (CEN, 2008), but included in EN 15978 (CEN, 2011b) • Lifts • Escalators • Safety and security installations • Communication systems Any building-integrated technical systems consuming energy that are necessary for the technical and functional performance of the building must be included in module B6 operational energy use and reported and communicated separately.
Optional in EN 15978	**Category 3: Non-building-related energy (optional inclusion):** • Any plug-in appliances, i.e. plug or tenant small power loads Energy use of appliances that are not building related but included in the energy simulation must be reported and communicated separately.

8.2.2 Energy supply

EN 15978 (CEN, 2011b) attributes the generation of on-site energy using the following rules:

- Site-generated energy that is used within the building is assumed to satisfy firstly the energy end uses within the building-related energy demand (categories 1 and 2 in Table 4).
- Subsequent to fulfilling all building-related energy demands, any remaining on-site energy generation is used to satisfy non-building-related energy demand (category 3 in Table 4).
- Having satisfied all building-related and non-building-related operational energy demands, any additional on-site generated energy is then exported. However, in reality, there is almost always a demand to import energy at times to satisfy the building operational energy demand, while at other times, the building may generate energy in excess of its needs that can be exported. This mismatch between energy demand and supply may be due to insufficient on-site generation capacity or due to peak demand/supply imbalances. In this situation, EN 15978 (CEN, 2011b) requires that the total import of energy is considered. Excess site-generated energy that is exported should not be subtracted from the import of energy to derive a net figure. Instead, the environmental benefit or load of energy generated on site and exported is reported in module D, if calculated. For further information about module D, please see BRANZ Study Report SR349 (Dowdell & Berg, 2016).

Thus, module B6 summarises total environmental impacts as a result of the supply of energy needed to meet building energy demand. Any supply of energy that is in excess of the building's demand, and the benefit or load as a result of the supply of this energy, is reflected in module D. This is depicted in Figure 6, based on EN 15978 (CEN, 2011b).

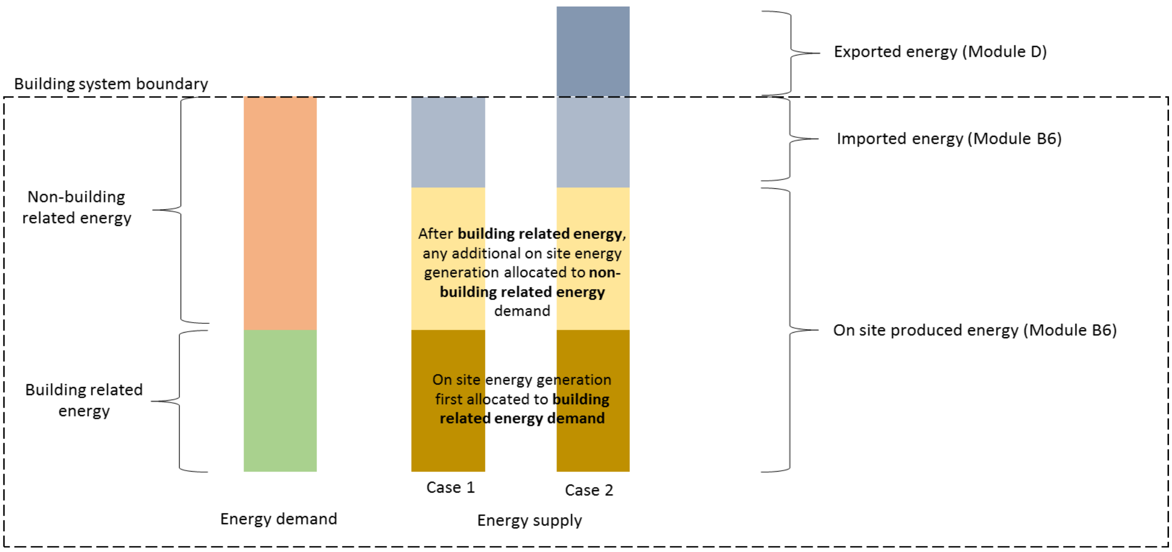

Figure 6. Allocation of energy supply produced within the building system boundary.

8.2.3 Energy modelling in *LCAQuick – Office*

The only on-site energy generation capacity option available in *LCAQuick – Office* is photovoltaics supplying electricity. Expanding on Figure 6, the way that *LCAQuick – Office* allocates photovoltaic electricity supply is summarised in Figure 7.

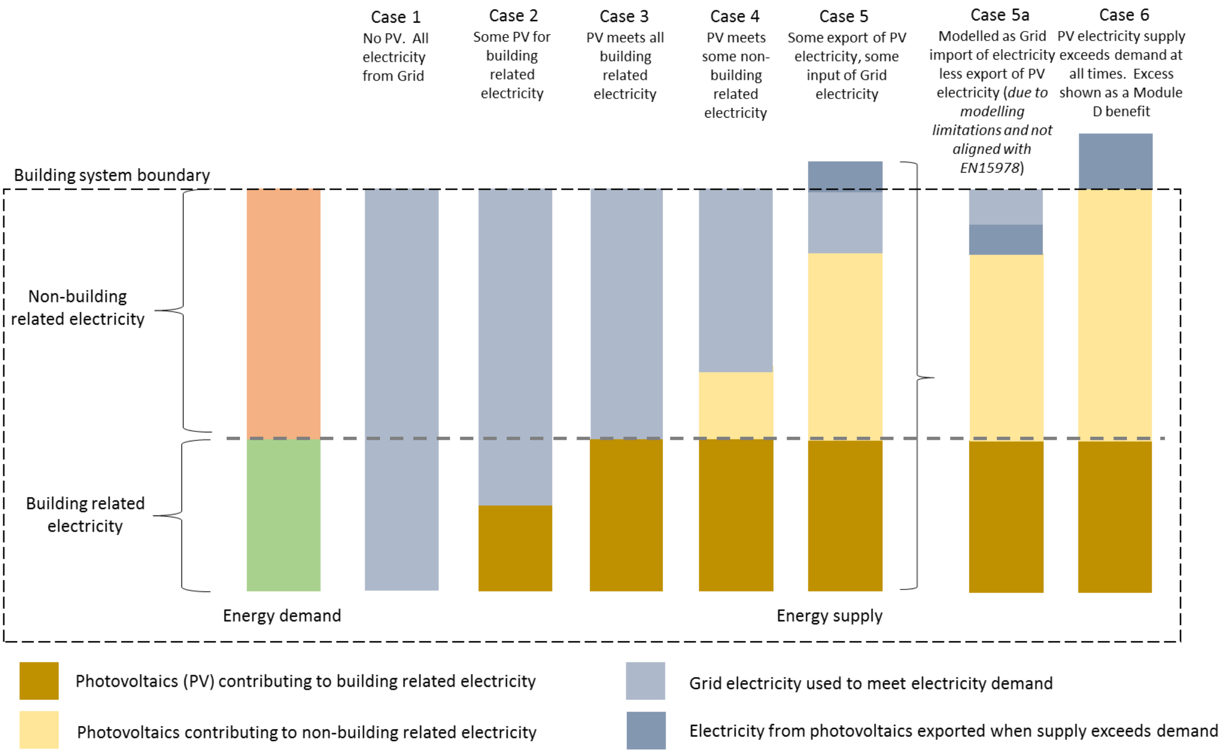

Figure 7. Summary of how electricity supply is modelled in *LCAQuick – Office*.

The calculation of environmental impacts associated with electricity supply is in accordance with EN 15978 (CEN, 2011b) in cases 1 to 4 and case 6 in Figure 7. These cover situations when:

- all electricity is derived from the grid (case 1)
- some electricity from on-site photovoltaics meets building-related electricity demand (case 2)
- all electricity from on-site photovoltaics meets building-related electricity demand (case 3)
- electricity from on-site photovoltaics meets all building-related electricity demand and some non-building-related electricity demand (case 4)
- electricity from photovoltaics always meets demand for electricity from building-related and non-building-related demand (no import of grid electricity), and excess supply is exported (case 6).

Case 5 deviates from the requirements of EN 15978 (CEN, 2011b) due to modelling limitations. EN 15978 (CEN, 2011b) requires that the environmental impacts of import of any grid electricity are accounted for in module B6 and any benefits (or loads) as a result of export of electricity from photovoltaics are accounted for in module D, if calculated.

In cases 1 to 4, on-site photovoltaic electricity generation contributes to meeting electricity demand (calculated using energy simulation models created in dynamic thermal simulation software such as EnergyPlus), and the balance comes from grid electricity. In case 6, on-site photovoltaic electricity generation exceeds demand at all times during a simulated year, and the excess electricity from photovoltaics substitutes for low-voltage New Zealand grid electricity generation and distribution in module D.

As required by EN 15978 (CEN, 2011b), on-site photovoltaic electricity generation first meets building-related electricity demand, followed by non-building-related electricity demand.

Case 5 illustrates a situation in which a proportion of electricity demand is met by grid electricity imported at particular times of the day and/or year in order to supply demand peaks caused by building users' temporal consumption patterns, for example, through use of lighting and electrical appliances (Sartori, Napolitano & Voss, 2012). This imported electricity is required to meet demands not being fully satisfied by the on-site generation, for example, the photovoltaics not generating electricity at night for lighting. However, at other times of the day and/or year, the photovoltaics supply too much electricity for building needs, and at these times, the photovoltaic-generated excess electricity is exported to the grid.

Thus, at certain times during the year, grid electricity is sometimes imported and photovoltaic-generated electricity is sometimes exported, with the situation at any specific time being dependent on the amount of electricity being generated by the photovoltaics and the demand for electricity in the building.

In this case, EN 15978 (CEN, 2011b) requires that all grid electricity that is imported during a year is accounted for in module B6 and the benefit of exporting photovoltaic-generated electricity to the grid is accounted in module D, if calculated (for example, by subtracting an equivalent amount of grid-generated and distributed electricity).

LCAQuick – Office is focused on early building design when energy demand can be modelled based on a 'performance sketch' (Donn, Selkowitz & Bordass, 2012) of a proposed building, and consideration may be given to potential for photovoltaic capacity based on available roof or site area and issues such as orientation and shading by neighbouring buildings or topography. At this stage of design, it is more likely that energy simulation results will be based on an annual balance and less likely that they will be analysed based on hour-by-hour electricity demand and supply over a year (which would be necessary in order to properly consider case 5).

For this reason, *LCAQuick – Office* takes the total calculated demand for electricity from an energy simulation model and subtracts the electricity available from photovoltaic supply over a year, based on the photovoltaic capacity (regardless of whether this supply is used in the building or exported). The effect of this simplification, which is made to align with the form of energy simulation data likely to be available during concept and preliminary design, is to under-report environmental impacts in module B6, since only environmental impacts of grid electricity in excess of total photovoltaic supply (either used in the building or exported) are accounted for, as illustrated in case 5a.

If results are considered as the total of modules A1 through to C4, plus module D, then there is no effect. This simplifying approach aligns with the International Energy Agency's definition for net zero-energy buildings, which states these are "buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid" (Marszal & Heiselberg, 2011).

8.3 New Zealand grid electricity

Sacayon Madrigal (2016) has developed an LCA model for New Zealand grid electricity at low, medium and high voltage. This model has been used to develop a dataset based on a 3-year average, spanning the years 2012 to 2014. The dataset is provided for 1 kWh of low-voltage grid electricity delivered to a building and is provided as:

- an LCI (in different formats).
- a summary of environmental indicators.

Base load supplied to the New Zealand grid is primarily provided from hydroelectric schemes with peak load being met by fossil fuels such as coal and gas. Therefore, the environmental impact of electricity generation and distribution in New Zealand can vary yearly depending on the amount and distribution of rainfall and therefore the capacity available to hydroelectric schemes.

Using the model developed by Sacayon Madrigal (2016) and MBIE data (2013, 2014 and 2015) for net electricity generation and source, Table 5 illustrates how the grid greenhouse gas impact varied between 2012 and 2014.

Table 5. Variation in annual grid electricity greenhouse gas impact based on the Sacayon Madrigal model.

	2012	2013	2014
Greenhouse gas impact (kg CO_2eq./kWh low voltage delivered)	0.21	0.18	0.16

In drier years, there is greater reliance on fossil fuels. MBIE reports that, in 2012 the renewables contribution supplying the grid was 73% compared with nearly 80% in 2014. The balance came primarily from natural gas and, to a lesser extent, coal.

From an LCA perspective, this means that an LCI for grid electricity based on a 'dry' year (such as 2012) will have higher environmental impacts per kWh delivered than an LCI for a 'wet' year (such as 2014). As a result, building LCA results modelled with 2012 grid electricity will look quite different to building LCA results for a similar building but modelled with 2014 grid electricity.

Sacayon Madrigal (2016) looked at the effect of using a multi-year average to smooth out these annual variations. Based on the findings and Sacayon Madrigal's model, BRANZ has developed an LCI for New Zealand grid electricity based on a 3-year average (2012–2014).

Electricity use in office buildings is typically a significant contributor to overall environmental impacts across the life cycle. It is therefore necessary to use consistent grid electricity data for building LCA comparisons. The New Zealand grid electricity data provided on the BRANZ website for the calculation of impacts associated with electricity use in module B6 has been developed for this purpose. This will help to ensure consistency when calculating building LCA environmental impacts.

The grid electricity data is provided in Excel (plus other formats) and can be downloaded from the BRANZ website at www.branz.co.nz/buildingLCA. It is used to calculate environmental impacts from electricity use in module B6 in *LCAQuick – Office*.

Further information about the grid electricity data is available in the BRANZ Study Report SR350 (Berg, Dowdell & Curtis, 2016).

9. Module B7 water use

The EN 15978 (CEN, 2011b) standard requires that all water use and its treatment must be included for the normal operation of the building, excluding maintenance, repair, replacement and refurbishment. Water uses to be included are:

- drinking water
- water for sanitation
- domestic hot water
- irrigation of any landscape areas
- water for heating, cooling, ventilation and humidification
- other specific uses, such as fountains or swimming pools.

The standard requires that water use arising from non-building-related appliances, such as dishwashers or washing machines, if included, shall be reported separately.

The datasheet entitled *NZ WBWLF – Module B7 water use [version number],* which can be downloaded from the BRANZ website at www.branz.co.nz/buildingLCA, provides benchmark water demand figures for office buildings based on measurement. Benchmark data is provided on the basis of cubic metres of water per m^2 net lettable area per year.

Data is provided for Auckland, Wellington and Christchurch. Data for Auckland and Wellington is based on measurement, while data for Christchurch is an estimate only, derived as the sample median of the Auckland and Wellington data combined.

All data has been obtained from Bint (2012).

This data comprises total water use in the measured buildings, which includes water use by non-building-related appliances, where these were present in measured buildings. Due to the nature of the data, it is not possible to separate this out, as required by the standard.

Similarly, the exterior of at least one building was washed while measurements were being made, and therefore water use arising from this maintenance activity for this one building is also included in the data.

For the purpose of calculating wastewater volume from a building, this can be taken as the same as the water demand into a building. Thus, the volumes provided in the water use datasheet can be used to represent the volume of water demanded by a building and the volume of wastewater exiting a building.

10. Module C1 building end of life waste

Module C1 covers demolition/deconstruction activities at a building's end of life. Examples of activities included in module C1 are:

- removing interior and exterior fittings and services with mechanical or powered hand tools and cutting/breaking equipment
- removing interior and exterior products and materials through use of heavy plant and equipment, including mobile and tower cranes
- collection, sorting and disposal of waste materials that may be routed to reuse, recycling or recovery activities or to landfill/cleanfill.

A datasheet has been developed entitled *NZ WBWLF – Module C1 building end-of-life waste datasheet [version number]*, which can be downloaded from the BRANZ website at www.branz.co.nz/buildingLCA. The datasheet provides typical and best-practice material reclamation rates by mass, diverted from landfill/cleanfill. Data is also provided showing typical and best-practice rates for reuse, recycling and energy recovery of these reclaimed materials.

For example, a typical figure of 50% diversion from landfill is provided for bricks, all of which is crushed for use as fill. The best-practice diversion rate increases to 100%, of which 90% is crushed for use as fill, with 10% being reused.

No distinction is made between landfill and cleanfill for the purposes of setting out a proportion of material that is disposed. Some foundation systems and crushed masonry, sand, rubble, dusts, powders and other friable materials may be buried and left on site. This material fate is also not separated from the landfill/cleanfill total.

It should be noted that the datasheet considers the building end of life and not necessarily the end of life of the materials that comprise its construction.

10.1 Data sources

Typical diversion rates from landfill at building end of life have been difficult to find and are largely based on judgement. More data was found for best-practice diversion rates, including case studies from the Target Sustainability website.[14] This provides demolition waste management case studies in the Canterbury region for projects carried out between 2009 and 2014, including some sites affected by the Canterbury earthquakes.

10.2 Material-specific information

Further information and assumptions about specific materials are provided in the following sections.

10.2.1 Materials associated with substrate materials

Materials such as paints that are used as protective coatings or decorative finishes associated with other materials such as timber are assumed to follow the end-of-life route of the substrate material. Where the substrate material goes through a recycling

[14] www.targetsustainability.co.nz

process, the coating or decorative finish may end up as part of the resulting recyclate or may be separated in the process and disposed.

Other materials that may be associated with substrates include adhesives, bonding agents, liquid-applied membranes, primers, sealants, mastics, bitumen, grouts and mortars that cannot readily be separated from the surfaces to which they are applied.

The typical end-of-life route for these kinds of materials is shown in the datasheet as landfill. Grouts and mortars are assumed to be crushed with the substrate materials with which they are associated to produce fill material.

10.2.2 Blocks and bricks

Hollow and solid concrete and masonry blocks together with concrete pavers can be recycled by crushing for use as fill material. If bricks/blocks are whole and clean, they have the potential for reuse as masonry units in another application. This is reflected in the 10% reuse figure in the best-practice data.

Hollow blocks when used for non-structural purposes can be reused (if deconstructed rather than demolished), although once filled with concrete, hollow blocks cannot be recovered whole. Damaged blocks, concrete and other masonry products can readily be crushed and used as fill.[15]

Reinforcing steel can be removed from concrete with a crusher. If the crusher is of sufficient capacity, this potentially allows 100% recycling of both the steel and the concrete from reinforced concrete. This is assumed for the best-practice option.

Chips and gravel, tiles and stone can also be reused or crushed.

10.2.3 Timber

Timber can be reused if in sufficient lengths or sheet sizes (typically 600 mm for timber lengths)[16] together with boards, planks and some prefabricated systems. This is dependent on the complete removal of nails and other fixings. Complete removal of fixings is also required if the timber is to be reprocessed. However, if small sections are being extracted for dwangs, bracing or unspecific uses, removal of all nails may be less important.

Untreated timber can also provide feedstock for energy recovery. However, a significant problem is the inability to readily differentiate treated from untreated timber (Rhodes & Dolan, 2010). Some facilities (such as cement manufacture) can obtain resource consent to combust timber waste, including some treated timber waste, for recovery of energy. The amount of treated timber that is processed in this way is limited due to the presence of heavy metals such as copper and chromium and the presence of arsenic in CCA-treated timber (Environment Canterbury, 2013). Separation of timber according to treatment is also difficult because timber brands and identification dyes (used since 2003) were not always applied to timber, can fade and may have been removed from short lengths.

[15] www.targetsustainability.co.nz
[16] www.branz.co.nz/REBRI

10.2.4 Sheet materials

Sheet products such as gypsum plasterboard, glass fibre-reinforced cement panels and fibre-cement sheets have the potential for greater diversion from landfill than is currently typical. This may be due to the potential for some reuse (for fibre-cement sheets) or recycling by crushing (if asbestos free) to form fill materials.

Gypsum is used as a soil conditioner and as an additive to compost when uncontaminated (Ministry for the Environment, 2008). Presently, no facilities accept waste plasterboard from demolition, given the likelihood of contamination with asbestos (formerly used as a constituent of some gypsum boards), paints (including lead-based paints), paper and other surface finishes. Best-practice case studies already exist that demonstrate high recycling rates either through soil conditioning or feedstock to cement production.

When gypsum is buried and anaerobically decomposes, it can produce hydrogen sulphide (Lawrence-Sansbury & Boyle, 2008).

10.2.5 Insulation

Bulk insulation materials are only able to be reused or recycled when they are reasonably clean. Therefore, a small provision is made for reuse in the datasheet.

However, vermin including rats and birds may be found in bulk insulation, and their spoor and accumulation of nesting materials can be hazardous.[17] Bulk insulation materials are relatively inert (glasswool, polyester, polystyrene) and can compress when buried. However, these materials are difficult to handle because of their bulk (even if they are lightweight). Sheep wool will decompose rapidly. However, other bulk insulants will not and may create toxic compounds in anaerobic conditions. Foil-based products can enter metal waste streams if they can be separated from co-mingled materials.

Due to the inherent difficulties of recycling insulation products derived from deconstructed or demolished buildings, we assume the majority of material goes to landfill in both typical and best-practice scenarios.

[17] I Cox-Smith, personal communication, following publication of the BRANZ Study Report SR232 (Cox-Smith, 2010).

References

Berg, B. Dowdell, D. & Curtis, M. (2016). *New Zealand whole-building whole-of-life framework: Development of reference office buildings for use in early design*. BRANZ Study Report SR350. Judgeford, New Zealand: BRANZ Ltd.

Bint, L. E. (2012). *Water performance benchmarks for New Zealand: Understanding water consumption in commercial office buildings*. Doctoral thesis, Victoria University of Wellington, New Zealand.

Building and Construction Productivity Partnership. (2014). *New Zealand BIM handbook: A guide to enabling BIM on building projects*. Wellington, New Zealand: BIM Acceleration Committee.

CEN. (2008). EN 15603: *Energy performance of buildings. Overall energy use and definition of energy ratings*.

CEN. (2010). EN 15643-1: *Sustainability of construction works. Sustainability assessment of buildings. Part 1: General framework*.

CEN. (2011a). EN 15643-2: *Sustainability of construction works. Assessment of buildings. Part 2: Framework for the assessment of environmental performance*.

CEN. (2011b). EN 15978: *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method*.

CEN. (2012a) EN 15643-3: *Sustainability of construction works. Assessment of buildings. Part 3: Framework for the assessment of social performance*.

CEN. (2012b). EN 15643-4: *Sustainability of construction works. Assessment of buildings. Part 4: Framework for the assessment of economic performance*.

CEN. (2013). EN 15804 (2012 + A1): *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products*.

Cox-Smith, I. (2010). *Using infrared thermal imaging to audit retrofitted wall insulation in houses*. BRANZ Study Report SR232. Judgeford, New Zealand: BRANZ Ltd.

Dolan, P. J., Lampo, R. G. & Dearborn, J. C. (1999). *Concepts for reuse and recycling of construction and demolition waste.* USACERL Technical Report 99/58. Springfield, VA: Construction Engineering Research Laboratories, US Army Corps of Engineers.

Donn, M., Selkowitz, S. & Bordass, B. (2012). The building performance sketch. *Building Research & Information*, *40*(2), 186–208. doi:10.1080/09613218.2012.655070

Dowdell, D. & Berg, B. (2016). *New Zealand whole-building whole-of-life framework: An overview*. BRANZ Study Report SR349. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2013). *Application of environmental profiling to whole building whole of life assessment – a plan for New Zealand*. BRANZ Study Report SR275. Judgeford, New Zealand: BRANZ Ltd.

Dowdell, D. (2014). New Zealand whole building whole of life framework: Life cycle assessment-based indicators. BRANZ Study Report SR293. Judgeford, New Zealand: BRANZ Ltd.

Environment Canterbury. (2013). *Treated timber waste minimisation project – Milestone 1: Industry overview*. Christchurch, New Zealand: Author. Retrieved from http://ecan.govt.nz/publications/Reports/treated-timber-waste-minimisation-project-report.pdf

ISO. (2006). ISO 14040: *Environmental management – Life cycle assessment – Principles and framework*.

ISO. (2007). ISO 21930: *Sustainability in building construction – Environmental declaration of building products*.

ISO. (2008). ISO 15392: *Sustainability in building construction – General principles*.

ISO. (2010). ISO 21931-1: *Sustainability in building construction – Framework for methods of assessment of the environmental performance of construction works – Part 1: Buildings*.

ISO. (2011). ISO 21929-1: *Sustainability in building construction – Sustainability indicators – Part 1: Framework for the development of indicators and a core set of indicators for buildings*.

Komatsu, Y. & Endo, K. (2000). *Lifetime and life cycle cost estimation of Japanese detached house*. Presented at the Second Japan-Scandinavia Seminar on Building Technology, Majvik, Masala, Finland, 25–26 May.

Komatsu, Y. (2013). Service lives of building – actual lifespans determined by factual investigation. *The Japan News by The Yoiuru Shinbun.* Retrieved on 16 September 2014 from http://www.yomiuri.co.jp/adv/wol/dy/opinion/earthquake_120213.html.

Lawrence-Sansbury, D. & Boyle, C. (2008). *The feasibility and practicalities of recycling gypsum plasterboard waste in New Zealand*. Retrieved from http://www.wasteminz.org.nz/wp-content/uploads/RECYCLING-GYPSUM-PLASTERBOARD-WASTE-IN-NEW-ZEALAND.pdf

Marszal, A. J. & Heiselberg, P. (2011). *Zero energy building definition – a literature review*. A technical report of subtask A, International Energy Agency, Joint Project-Task 40/Annex 52 Net Zero Energy Buildings. Retrieved from http://www.iea-shc.iea-shc.iea-shc.iea-shc.org/data/sites/1/publications/T40A52-STA-Marzal-Report-2012-09.pdf

MBIE. (2013). *Energy in New Zealand 2013–2012 calendar year edition*. Wellington, New Zealand: Ministry of Business, Innovation and Employment.

MBIE. (2014). *Energy in New Zealand 2014–2013 calendar year edition*. Wellington, New Zealand: Ministry of Business, Innovation and Employment.

MBIE. (2015). *Energy in New Zealand 2015–2014 calendar year edition*. Wellington, New Zealand: Ministry of Business, Innovation and Employment.

Ministry for the Environment. (2008). *Waste plasterboard composting literature review.* Wellington, New Zealand: Author.

O'Connor, J. (2004). *Survey on actual service lives for North American buildings*. Presented at the Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, USA.

Rhodes, S. & Dolan, L. (2010). *Recovery and disposal options for treated timber*. Retrieved from http://www.wasteminz.org.nz/wp-content/uploads/Scott-Rhodes.pdf

Sacayon Madrigal, E. E. (2016). *Assessment of the life cycle-based environmental impacts of New Zealand electricity*. Master's thesis. Massey University.

Sartori, I., Napolitano, A. & Voss, K. (2012). Net zero energy buildings: A consistent definition framework. *Energy and Buildings*, *48*, 220–232. doi:10.1016/j.enbuild.2012.01.032

van Nunen, H. & Mooiman, A. (2011). Improved service life predictions for better life cycle assessments. *Proceedings of 2011 Helsinki World Sustainable Building Conference*.

Appendix A: Potential environmentally significant construction site activities

BRANZ had meetings with a Hawkins Construction quantity surveyor over a 3-month period with the aim of determining construction site activities with potentially significant environmental impacts.

Site activities were classified based on the Co-ordinated Building Information (CBI) system, which was provided to BRANZ, under licence, by Construction Information Limited.[18]

Hawkins was asked to identify construction site activities with potentially significant environmental impacts. For the purposes of this work, activities identified as having potentially significant environmental impacts were based on their:

- use of energy
- generation of waste
- use of water
- use of ancillary materials (additional materials required that are not consumed during fitting or installation) or consumables (additional materials required that are consumed during fitting or installation).

Activities in the CBI were screened based on these criteria using Hawkins' judgement, in order to provide a list of activities with potentially significant environmental impacts. Significance here is from a construction site perspective, not a whole-building perspective. In practice, it was found to be difficult to allocate processes to the last category above, so no practices were selected based on this.

The assessment was made with consideration of typical technologies used in mid-rise office building[19] construction in New Zealand in 2014 on brownfield flat urban sites.

The work undertaken is subjective and based on judgement and is provided for information only in Table 6.

[18] www.masterspec.co.nz/industry-resource/cbi-classification-and-coding-overview-1130.htm
[19] Taken as a 6-storey building with a footprint of 400 m^2.

Table 6. Work sections identified with potentially significant environmental impacts.

CBI 1-digit code	CBI 4-digit code	Activity	Energy	Waste	Water
2 Site	2231	Ground preconsolidation	✓		
	2232	Mechanical ground stabilisation	✓		
	2241	Excavating and filling	✓	✓	
	2311	Cast in place concrete piles	✓		
	2312	Driven precast concrete piles	✓		
	2313	Driven steel piles	✓		
	2314	Screwed steel piles	✓		
	2341	Diaphragm construction	✓	✓	✓
	2343	Ground anchors		✓	
	2362/4264	Concrete masonry foundation wall			✓
3 Structure	3122	Sprayed concrete		✓	
	3123	Surface finish for concrete			✓
	3151	Making formwork for concrete construction			✓
	3323	Concrete blocks			✓
	3411	Structural steel	✓		
4 Enclosure	4111	Mastic asphalt tanking	✓		
	4211	Curtain wall installation	✓		✓
	4215	Concealed grid panel cladding	✓		
	4216	Glazed walling, vaults etc	✓		✓
	4231	Fibre cement cladding		✓	
5 Interior	5113	Plasterboard linings		✓	
	5212	Timber frame partitions		✓	
7 Services	5323	Suspended ceiling with services		✓	