Athena Sustainable Materials Institute

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Brock Commons Tallwood House, University of British Columbia

An Environmental Building Declaration According to EN 15978 Standard

Photo courtesy of Lara Shecter

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About Environmental Building Declarations
An environmental building declaration (EBD) is a summary report of comprehensive environmental impact data for a building, declaring life cycle impacts according to a standardized format. The purpose is typically for transparent, concise, public disclosure of performance data. Each EBD helps raise awareness about the value of LCA in bringing a data-driven perspective to sustainable design, and the need for performance accountability. An EBD also serves an advocacy role for standardization in the practice and reporting of whole-building LCA. However, adherence to such standards does not yet enable easy comparability between EBDs for different buildings. As with environmental product declarations, a number of factors make it very difficult to compare results across EBDs. While this may change as standards and practices evolve, the primary benefit of an EBD is in measurement, disclosure, and future application of lessons learned.

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1.0 General Information on the Assessment

This document presents a whole-building environmental life cycle assessment (LCA) of the University of British Columbia (UBC) **Brock Commons Tallwood House** (herein referred to as Tallwood House), a student residence building in Vancouver, British Columbia. The LCA was commissioned to publicly declare the environmental performance of the building.

The assessment has been conducted in conformance with the Committee for European Standardization (CEN) standard **EN 15978**[1], which stipulates an LCA-based calculation method and reporting requirements for whole-buildings or building parts. While European in scope, EN 15978 provisions are quickly becoming the standard for whole-building LCA worldwide. We therefore applied our North American interpretation of EN 15978 as a suitable methodological choice to meet the purpose of the assessment.

Table 1: Assessment Information Summary

Client for assessment	University of British Columbia
Assessor	Matt Bowick (M.A.Sc.), Senior Research Associate, Athena Sustainable Materials Institute
Internal verifier	Jamie Meil (M.Sc.), Research Principal, Athena Sustainable Materials Institute
Date of assessment	February 2017
Assessment timing	Use phase (occupancy commenced August 2017)
Period of validity	5 years

The scope of LCA is a cradle-to-grave analysis of the material effects of structure, envelope, interior partition, and finish assemblies, and operating energy use, over a 100-year period. The LCA primarily draws on data from the Athena Sustainable Materials Institute's ISO 14040/44 conforming *Impact Estimator for Buildings* software database, and augmented with the Institute's secondary databases and Environmental Product Declarations (EPDs). Life cycle impacts were evaluated according to TRACI v2.1 category mid-point characterization methodology[2] and the LCA modeling was performed with a customized Excel-based tool.

Seventeen indicators covering environmental impacts, resource use, waste, and output flows leaving the system are reported – see Table 2 for summary results of six environmental impacts. Various contribution and sensitivity analyses are provided, along with additional information, including avoided impacts and burdens occurring beyond the life cycle and carbon sequestration of wood and concrete products.

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[1] EN 15978:2011 *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.*

[2] http://www.epa.gov/nrmrl/std/traci/traci.html

Table 2: 100-year Tallwood House Life Cycle Environmental Impact Summary

EN 15978 Environmental Impact Indicator	Unit	Total
Global warming potential	kg CO_2 eq.	2.99E+07
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	1.08E-01
Acidification potential of land and water	kg SO_2 eq.	1.84E+05
Eutrophication potential	kg N eq.	4.30E+04
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.50E+06
Abiotic resource depletion potential of fossil fuels	MJ surplus	6.59E+07

Table 2 note: eq.=equivalent

1.1 Purpose of the Assessment

As per EN 15978, the goal of the assessment is to quantify the environmental performance of the object of assessment by means of compiling environmental information.

This assessment was commissioned for the following purpose:

To publicly declare the environmental performance of Brock Commons Tallwood House.
This document presents a model derived estimate of the environmental performance of Tallwood House according to a standardized format to publicly communicate results in a transparent and comparable manner. The intended use of this assessment is for educating/informing building sector stakeholders about the environmental implications of the Tallwood House design, and wood-hybrid high-rise construction in general.

Please note: comparisons between building assessments are difficult to make due to possible differences including: scope (e.g. system boundary), building location, study period, and data sources.

1.2 Identification of the Building

The building of study is UBC Tallwood House, an 18-storey, 15,120 m^2 (162,750 ft^2) structure located at 6088 Walter Gage Road, Vancouver, British Columbia – see Table 3 for the project directory and Figure 1 through Figure 4 for building photos.

Tallwood House will provide 272 single bed studios, and 33 4-bed suite accommodations for UBC students, along with study, social, and lounge spaces.

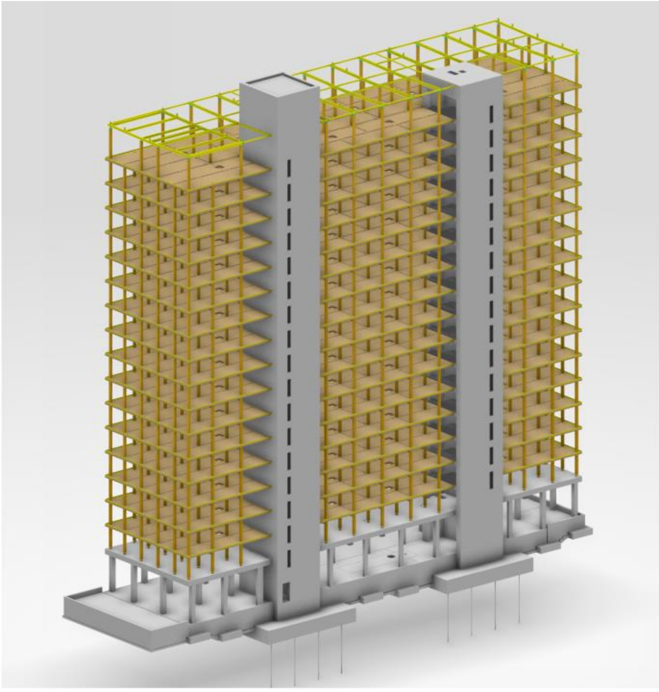
1.3 Assessment Verification

While studies compliant with EN 15978 do not specifically require verification, the standard stipulates a set of requirements when it is to be performed. This LCA has been internally verified for compliance with the standard.

Statement regarding verification of this assessment: *The internal verifier has determined that this LCA-based study meets the requirements for methodology, data, and reporting in EN 15978, and is consistent with its principles.*	Jamie Meil, Research Principal, Athena Sustainable Material Institute

Table 3: Project Directory

Owner	University of British Columbia
Architect	Acton Ostry Architects Inc.
Tall Wood Advisor	Architekten Hermann Kaufmann ZT GmbH
Structural Engineer	Fast+Epp
Fire Science/Building Code	GHL Consultants Ltd.
Building Science	RDH Building Science
Mechanical/Electrical/Sustainability	Stantec
Construction Management	Urban One Builders
Project Management	UBC Properties Trust
CLT and Glulam Manufacturer	Structurlam Products
Wood Installer	Seagate Structures
Landscape	Hapa Collaborative
Geotechnical	Geopacific Consultants Ltd.
Civil	Kamps Engineering
Street Lighting	GNEC
Surveyor	Murray & Associates Ltd.
Elevator	Apex
Acoustic	RWDI Air Inc/ DLA



Rendering courtesy of Fast + Epp and UBC

Figure 1: Rendering of Structure

Photo courtesy of UBC

Figure 2: Interior During Construction

Photo courtesy of naturally:wood

Figure 3: Exterior During Construction

Photo courtesy of naturally:wood

Figure 4: Exterior During Construction

2.0 General Information on the Object of Assessment

2.1 Functional Equivalent

EN 15978 requires identification of a functional equivalent for the building to enable a valid basis for future comparisons to other buildings. According to EN 15978, a **functional equivalent** is “the quantified functional requirements and/or technical requirements for a building or an assembled system (part of works) for use as a basis for comparison.” In other words, the functional equivalent is a set of design criteria that both buildings must have in common to ensure an apples-to-apples comparison.

Table 4 defines the functional equivalent of Tallwood House.

Table 4: Functional Equivalent

Building type	Multi-unit residential building, student residence
Technical[3] and functional[4] requirements	Part 3 British Columbia Building Code 2012, Site Specific Regulation (BC reg. 182/2015); LEED Gold certified (pending)
Pattern of use	Study and social space, and residence for a maximum capacity of 404 students
Required service life[5]	100 years[6]

2.2 Reference Study Period

While the functional equivalent requires a statement of a building's required service life, it doesn't necessarily have to be the same as the **reference study period**, which is defined in EN 15978 as "the period over which the time dependent characteristics of the object of assessment are analyzed." For this declaration, the reference study period of the assessment is the same as the assumed required service life of the building, 100 years.

[3] Defined in EN 15978 as the "type and level of functionality of a building or assembled system which is required by the client and/or by users and/or by regulations."
[4] Defined in EN 15978 as "type and level of technical characteristics of a construction works or an assembled system (part of works), which are required or are a consequence of the requirements made either by the client, and/or by the users and/or by regulations."
[5] Defined in EN 15978 as the "service life required by the client or through regulations."
[6] Based on a 100-year service life requirement for the building structure, as per UBC Technical Guidelines.

2.3 Object of Assessment Scope

The **object of assessment** is a definition of what is to be analyzed; EN 15978 stipulates that "the object of assessment is the building, including its foundations and external works within the curtilage of the building's site, over the life cycle." However, when conducting whole-building LCA, not all aspects of a building can typically be assessed given finite project resources and data limitations.

The object of assessment of this study is Tallwood House and includes materials from the construction elements noted in Table 5, along with the operating energy and water end-uses noted.

Notable material omissions from the included elements are:

- Recessed entry mat;
- Window sill finishes;
- Non-structural connections;
- Surface treatments (e.g. fire retarding coatings);
- Adhesives and sealants;
- Soffit, drain covers, vents, roof hatches, etc.;
- Temporary works used during construction and demolition/de-construction phases (e.g. shoring, formwork).

Table 5: Object of Assessment Summary

Material Use (UniFormat)	**Operating Energy Use** (end-uses)	**Operating Water Use** (end-uses)
• A1010 Standard Foundations • A1020 Special Foundations • A1030 Slab on Grade • A2020 Basement Walls • B1010 Floor Construction • B1020 Roof Construction • B2010 Exterior Walls • B2020 Exterior Windows • B2030 Exterior Doors • B3010 Roof Coverings • B3020 Roof Openings • C1010 Partitions • C1020 Interior Doors • C2010 Stair Construction • C3010 Wall Finishes • C2020 Stair Finishes • C3020 Floor Finishes • C3030 Ceiling Finishes	• Space Heating • Space Cooling • Ventilation (fans) • Domestic Hot Water • Lighting (interior and exterior) • Auxiliary Energy (elevators) • Non-building-integrated (equipment)	• Water closets • Urinals • Showers • Lavatory taps • Kitchen taps

2.4 Building Design Description

The building's structural system consists of a metal deck roof on steel and glulam framing, cross laminated timber (CLT) floor panels supported by glulam columns (third through eighteenth floors), a second floor concrete suspended slab supported by concrete columns, and a slab on grade at the ground floor. The building's lateral resistance is provided by the two concrete stair/elevator cores.

The building's perimeter is supported by concrete foundation walls on strip footings; columns along the perimeter are supported by piers integrated into the foundation walls (i.e. wall thickenings) and pad footings, whereas interior columns are supported by concrete piers at the basement level and pad footings. The stair/elevator cores are supported by large raft footings with soil anchor tension reinforcement.

Fenestration includes punched windows with 2.56 W/m2 °C U-value (0.45 Btu/hr-ft2-°F) and solar heat gain coefficients (SHGC) of 0.45 on levels 2 through 18 and a level 1 curtain wall system with 2.56 W/m2 °C U-value (0.45 Btu/hr-ft2-°F) and solar heat gain coefficients (SHGC). Fenestration makes up less than 40% of the wall envelope. Perimeter walls are otherwise a Trespa clad prefabricated panel system, which generally has a 2.94 RSI value (R-value of 16.7). The roof envelope consists of a modified bitumen membrane assembly with 3.52 RSI value (R-value of 20).

Partitions are for the most part light gauge steel stud walls with fibreglass batt sound attenuation insulation and 16 mm or 12mm gypsum board. Interior wall and ceiling finishes are generally paint on gypsum board with some ceiling tile and floor finishes include carpet, resilient flooring and ceramic tile.

Table 15 (Appendix B) presents a more detailed summary of the construction element assemblies – see Table 16 (Appendix C) for the resulting whole-building bill of materials. Material quantities were calculated by UBC staff, with some support from Athena, based on the building's BIM model, "Issued for Construction 2" architectural drawings produced by Acton Ostry Architects Inc. (dated January 29,2016), and "Issued for Construction" structural drawings produced by Fast + Epp (dated November 9, 2015).

The building is connected to UBC's *Academic District Energy System* (ADES), a network of hot water piping across the UBC Vancouver campus. The ADES provides Tallwood House with hot water for space heating of the common areas and domestic hot water needs – suites are heated with electric baseboards. Cooling is provided by operable windows. When windows are opened the heating system is automatically shut off.

The heating, ventilation and air conditioning (HVAC) system includes supply and exhaust air and stair pressurization. The supply and exhaust air is distributed horizontally at the 18^{th} floor and vertically within mechanical shafts. Each suites ductwork is located between the units.

3.0 Statement of System Boundary Used in the Assessment

The assessment **system boundary** defines which life cycle activities (undergone by the object of assessment) are to be included in the analysis. As illustrated in Figure 5, the system boundary according to EN 15978 is characterized by the temporal flow of the building life cycle – i.e. Product, Construction Process, Use, and End of Life stages. The various processes that occur at each stage are classified and grouped in **information modules** (or simply "modules"), labeled with alpha-numeric designations "A1" through "C4". This modular structure provides a consistent and transparent reporting format for building assessments as well as environmental product declarations (EPDs) in conformance with the standard EN 15804[7].

Accounting for the life cycle of a building is complete when all its constituent materials reach a state where they are no longer considered waste – an allocation methodology known as the *polluter pays*. The potential environmental benefit or burden arising from subsequent use of secondary materials and energy recovered from the system of study is optionally accounted for as additional information in module "D" – e.g. the net benefit of a reused wood beam substituting a new manufactured wood beam.

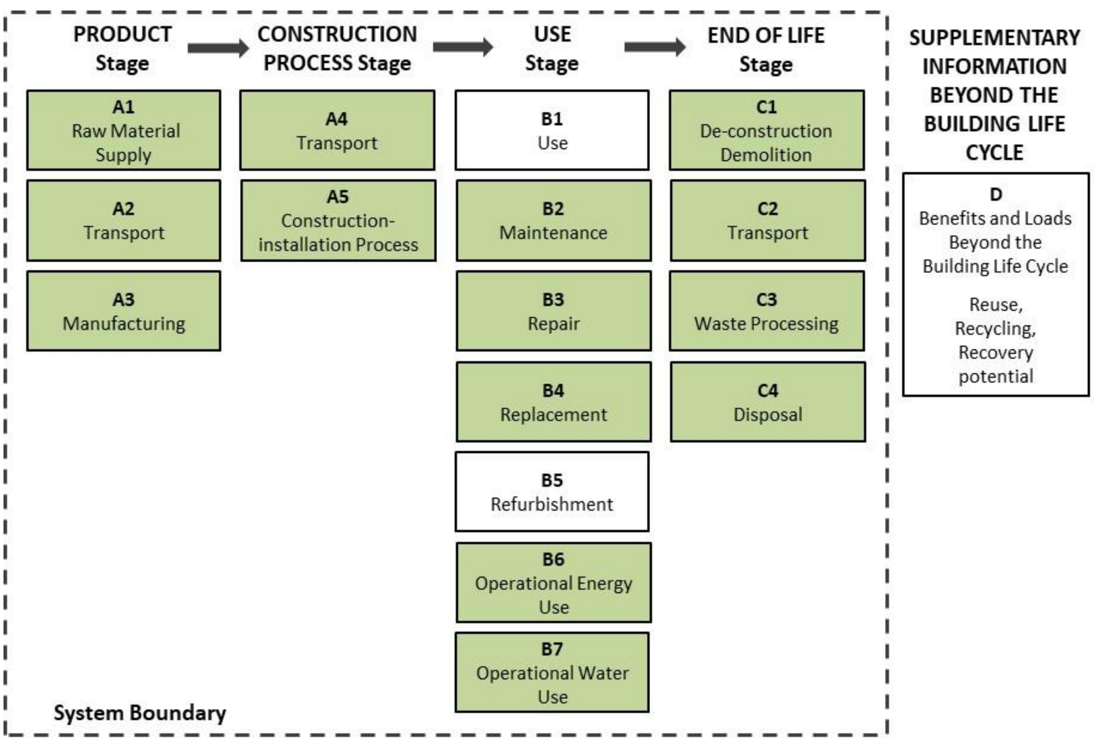


Figure 5: Assessment System Boundary

[7] EN 15804:2012 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products

The system boundary of this assessment is cradle-to-grave and includes the information modules shown as green boxes in Figure 5, and Table 6 provides further details about the various life cycle activities accounted for by each module.

Three modules were not included for the following reasons:

- **B1:** there is currently insufficient consensus in terms of methodology and data to practically quantify these effects for all products used in the building.
- **B5:** at this time, there is no known planned refurbishment for the building and no available scenario information on typical refurbishment activities for this type of building.

Table 6: Assessment System Boundary and Scope Summary

Information Module	Name	Included?	Processes Included
A1	Raw material supply	Y	primary resource harvesting and mining
A2	Transport	Y	transport up to manufacturing plant gate
A3	Manufacturing	Y	manufacture of raw materials into products
A4	Transport	Y	transport of materials to site
A5	Construction-installation process	Y	construction equipment energy use, and production, transport and waste management of materials lost during construction
B1	Installed product in use	N	not applicable
B2	Maintenance	Y	production, transport, construction and waste management of materials used for maintaining building components during use
B3	Repair	Y	production, transport, construction and waste management of materials used for repairing building components during use
B4	Replacement	Y	production, transport, construction and waste management of replaced materials during use
B5	Refurbishment	N	not applicable
B6	Operational energy use	Y	energy production, transportation and use
B7	Operational water use	Y	water supply and wastewater treatment facilities
C1	De-construction demolition	Y	demolition equipment energy use
C2	Transport	Y	transport of waste materials from site to disposal facilities; transport of steel to preprocessing and recycling facilities
C3	Waste Processing	Y	sorting/preprocessing facility equipment energy use
C4	Disposal	Y	landfill and incinerator energy use and site effects

This assessment assumes that once the material is either [1] separated for recycling, reuse, or energy recovery purposes or [2] disposed of (i.e. either via landfill or incineration), it has reached its end-of-waste state[8]. For example, a wood beam left on-site for the purpose of reuse has reached its end-of-waste state provided it does not require further sorting from other waste. In this case, no further environmental burdens (e.g. from transport to storage facility) associated with the beam are allocated to the building.

The one exception to this approach is recycled metal products, since the production stage of the LCI data used does not include preprocessing of secondary metal (scrap processing and transport). Therefore, steel preprocessing effects are allocated to the appropriate modules in which metal are recycled.

4.0 Statement of Scenarios Used in the Assessment

Because not all information is practically available to the assessor and because buildings have long and uncertain services lives, **scenarios** (i.e. assumptions) are required to provide a complete description of the building beyond the Product stage.

For this assessment, a scenario is defined as information generally required to calculate inputs for the process-based environmental data used. For example, the distance a material is transported to site is required to calculate the tonne*km input of the modal transportation life cycle inventory data (LCI) used in the assessment.

This section describes the scenarios assumed that are relevant to the object of assessment and its system boundary, and are based on current practice. ***All scenario tables can be found in Appendix D.***

4.1 Transport of Materials to Site

The assumed plant-to-site material transportation scenarios are presented in Table 17. The modes and distances for the following products were estimated based on the location of the project's product suppliers, and comprise the majority of the building's mass:

- Cast-in-place concrete;
- Cross laminated timber; glulam; and
- Aluminum extrusions and window frames.

Estimates for all other products are taken from either [1] the *Athena Transportation Database* (Vancouver location) or [2] an EPD (see Section 6.1 for which products apply).

[8] This is the same approach as that taken by the IE4B software.

4.2 Construction Energy Use

Estimated fuel use for construction activities has been calculated in two parts. For structure, fuel use estimates were calculated based on information from the *Athena Construction Energy Database.* Envelope and finish materials are assumed to be lifted by crane $^1/_2$ the height of the building in accordance with Equation (1):

$$F = 0.00037*M*h + M/500 + 0.83 \quad (1)$$

where,
F = diesel in liters
M = mass of material lifted in kg
h = height of material to be lifted in meters

Construction fuel usage is presented in Table 18.

4.3 Construction Material Wastage

On-site construction waste due to cut-offs, or unused, lost, or damaged materials require greater quantities of materials to be purchased than what is specifically required in the constructed building. The assessment accounts for these additional quantities by multiplying materials required by the building by *Construction Waste Factors*. The assumed scenarios presented in Table 19 are estimates from the *Athena Construction Waste Factor Database*.

4.4 Use Stage Material Use

Maintenance, repair and replacement activities (information modules B2, B3, B4, respectively) typically involve periodic tasks (i.e. material replacements) to ensure the continued functional performance of the building. This assessment calculates the number of times a task occurs over the lifetime of the building according to Equation (2), which is the methodology used by the IE4B software.

$$N_x = (S - F_x) / F_x \quad (2)$$

where,
N_x is the number of times task x occurs
S is the building reference study period (years)
F_x is the task frequency for task x (years)

This methodology typically results in only a percentage of the final task being allotted to the building. For example, if the service life of a building is 65 years and the replacement frequency of a window unit is 15 years, only 33% of the window replacement occurring at year 60 (5 years/15 years) is allotted to the building.

Equation (2) deviates from the methodology outlined in EN 15978. The standard requires that [1] only whole replacements are to be considered, and [2] if the remaining service life of the building is short in proportion to the estimated service of a product, the actual likelihood of the task shall take into account the required technical and functional performance for the product. In other words, the assessor may have to make value judgments as to whether the final task occurs. It is our opinion that this causes inconsistency between assessments.

Equation (3) was used to calculate the total material quantities replaced over the building lifetime:

$$Q_{x,y} = N_x M_y P_{x,y} \qquad (2)$$

where,

$Q_{x,y}$	is the total quantity of material y replaced due to task x
N_x	is the number of times task x occurs
M_y	is the total quantity of material y in the assembly
$P_{x,y}$	is the percent of M_y replaced due to task x

Task frequency (F_x) and percent of material replaced ($P_{x,y}$) estimates assumed are presented in Table 20, Table 21, and Table 22, along with the various sources used.

The reporting format and calculation methodology of the sourced task frequencies (F_x) and material use percentages ($P_{x,y}$) are not compliant with ISO standards 15686-1[9] and 15686-8[10], as required by EN 15978. However, it is our opinion that until service life planning is a more established practice in North America, the sources from which the estimates were developed are both consistent and of sufficient quality for this building assessment.

4.5 Operational Energy Use

The building consumes grid-supplied electricity on-site and hot water delivered by the University's *Academic District Energy System* (ADES). The annual operational energy use scenario presented in Table 23 was provided by UBC staff and is based on calibrated[11] estimates from simulations performed by EnerSys Analytics Inc.; the ADES fuel usage per MJ delivered hot water was provided by UBC staff.

It is assumed that this energy consumption represents a typical annual demand over the 100-year building service life. In other words, it is assumed that the building's energy systems, thermal performance, and local climate do not change over the 100-year reference study period. Similarly, it is assumed that purchased energy sources do not change over the building's required service life, e.g. purchased electricity is assumed to be generated using the same energy source mix.

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[9] ISO 15686-1:2011 Buildings and constructed assets - Service life planning - General principles and framework

[10] ISO 15686-8:2008 Buildings and constructed assets - Service life planning - Reference service life and service-life estimation

[11] Calibrated according to existing data (model vs. actual) from three previously constructed student residences.

4.5 Operational Water Use

The annual operational water use scenario presented in Table 24 reflects estimates calculated by UBC. Wastewater flows are assumed to be equal to the demand since [1] there is no water reported for irrigation, and [2] water consumed by occupants is assumed to make up a small portion of total usage. Water system technologies and their rate of use are assumed not to change over the 100-year required service life.

4.7 Demolition Energy Use

This assessment assumes that diesel-fueled equipment is used to demolish construction assemblies. The fuel use estimates for each building case found in Table 25 were calculated based on information from the *Athena Demolition Energy Database.*

4.8 Material Waste Outcomes

After a building assembly has been demolished and/or deconstructed, there are several possible outcomes for the resulting waste materials. The waste may be disposed of via landfill or incineration, or reused, recycled or converted to usable energy, and may undergo processing (e.g. sorting). Table 26 presents the assumptions used in this assessment.

4.9 Waste Transport

All landfilled waste materials are assumed to be transported to the *Vancouver Landfill*. Table 27 presents the assumptions used in this assessment.

5.0 Additional Information

This section presents the methods and assumptions used to quantify the additional environmental information reported in Section 8.4. This information has been treated separately from the core assessment because the topics addressed either are not part of the life cycle study or the methodologies used to calculate the information are not currently standardized within the EN 15978 calculation framework. ***All additional information scenario (i.e. assumption) tables can be found in Appendix D.***

5.1 Module D

Module D quantifies the future potential net benefit or load of materials and energy sources recovered from the building and exiting the system boundary. These output flows are assumed to substitute for materials or energy production from existing technologies and/or current practice.

This assessment estimates the potential benefits and/or loads from the fraction of concrete, steel, and aluminum products that are recovered for recycling.

Substitution effects were calculated according to Equation (4):

$$LCI_D = NF * PY * (lci_1 - lci_2) \quad (4)$$

where,

LCI_D is the module D substitution effects LCI of the secondary material/fuel

NF is the net output flow of the secondary material/fuel

PY is the process yield of the recycling, reuse, or energy recovery process (e.g. >1kg scrap is required to produce 1kg steel)

lci_1 is the unit process LCI (e.g. per-kg-product) for producing the material/ energy that is substituted

lci_2 is the unit process LCI for producing the materials/energy from secondary sources which substitutes primary production

The net output flow (NF) is the difference between the recovered secondary material/fuel leaving the product system and the secondary material/fuel that was used by the system, for all relevant information modules included in the life cycle of the object of assessment. It represents the net amount of secondary material/fuel added-to, or removed-from, the technosphere. The assumed net output flows presented in Table 28 were calculated with information from Athena databases.

PY (lci1 - lci2) is the net value of producing materials/energy via secondary vs. primary production, per unit net output flow.

This assessment assumes the following:

- **Recycled steel** materials substitute for primary metal production. PY (lci1 - lci2) is therefore the difference between primary and secondary metals production (i.e. the “scrap value”).
- **Recycled aluminum** materials substitute for primary metal production. PY (lci1 - lci2) is therefore the difference between primary and secondary metals production (i.e. the “scrap value”).
- **Recycled concrete** materials are crushed on-site and substitute for aggregate. PY (lci1 - lci2) is therefore the difference between the effects primary aggregate production (i.e. quarrying, crushing, transporting) and crushing of concrete. Relative transportation effects are assumed to be the same and ignored.

- **Reused wood** products (CLT, glulam, and PSL) are assumed to substitute primary production. PY (lci1 - lci2) is therefore the difference between primary production, and the effects of transporting, storing and processing the reused product. The effects of transport to site are assumed to be the same and ignored.

Substitution benefits and burdens for other materials are not considered in the assessment.

5.2 Carbon Sequestration

5.2.1 Biogenic Carbon Sequestration of Wood Products

This assessment accounts for the net biogenic carbon sequestration from landfilling of wood products. The global warming potential benefits of sequestration have been estimated using FPInnovation's *Carbon Tool B2C v2.18*[12] – see Table 29 for the assumed percentages of wood products landfilled, incinerated, and recycled at end of life and Table 29 other assumptions.

5.2.2 Concrete Carbonation

Carbon dioxide is a product of the chemical reactions that take place during cement production, a process known as calcination. Carbonation is the reverse chemical process, whereby CO_2 reacts with hydration products such as calcium hydroxides (CH) and calcium silicate hydrates (C-S-H) in the presence of water to produce calcium carbonate ($CaCO_3$).

The chemical reactions that occur are well-understood, but the speed at which the reactions occur in concrete products is still under study. Lagerblad[13] gives the depth of carbonated concrete as a function of time according to Equation (5), which is based on Fick's 1st Law of Diffusion:

$$x(t) = s * b * k * t^{0.5} \quad (5)$$

where,

x(t)	is the depth of carbonated concrete (mm) at time t
s	is a correction factor based on surface treatment and cover, which ranges between 0.7 and 1
b	is a correction factor based on the type and quantity of binder additive used, which ranges between 1.0 and 1.3
k	is the carbonation rate coefficient (mm/year$^{0.5}$), which ranges between 0.5 and 15 based on the concrete compressive strength and type of exposure
t	is the time elapsed (years)

[12] For more information on the tool used and its methodology, see: https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Pages/default.aspx

[13] Lagerblad, B. (2005). *Carbon dioxide uptake during concrete life cycle : State of the art*. Oslo: Nordic Innovation Centre.

The mass of CO_2 sequestered via carbonation is given by Equation (6) (Collins[14]):

$$m_{CO2}(t) = x(t) / 1000 * A * c * CaO * r * M \quad (6)$$

where,

$m_{CO2}(t)$	is the mass of CO_2 sequestered via carbonation at time t (kg)
x(t)	is the depth of carbonated concrete (mm) at time t
A	is the exposed surface area (m^2)
c	is the quantity of ordinary Portland cement in the concrete (kg/m^3)
CaO	is the calcium oxide (CaO) content of ordinary Portland cement, assumed by Collins to be 0.65
r	is the proportion of CaO in fully carbonated ordinary Portland cement converted to calcium carbonate, assumed by Lagerblad (2005) to be 0.75
M	is the molar fraction of CO_2/CaO, which is 0.79

Carbon sequestration from carbonation of concrete products has been quantified in accordance with the Equations (5) and (6) – Table 30 see for relevant assumptions.

Two carbonation values are reported:

1. Module A-C sequestration results include carbonation that occurs during the 100-year building use phase and 100 years of carbonation of the waste fraction that is landfilled. It is assumed that landfilled concrete waste is composed of 100mmx100mmx100mm rubble.
2. Module D sequestration results are the substitution credits that the recycled concrete waste fraction receives. The crushing of concrete is assumed to produce aggregate with a range of particle sizes as per Table 31. Over the course of the recycled aggregate's assumed 100-year service life, it becomes completely carbonated.

6.0 Environmental Data

6.1 Data Sources

Whole-building LCA typically draws on **environmental product declaration** (EPD)[15] and/or **life cycle inventory** (LCI)[16] environmental data sources.

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[14] Collins, F. (2010). Inclusion of carbonation during the life cycle of built and recycled concrete: influence on their carbon footprint. *The International Journal of Life Cycle Assessment*, *15*(6), 549–556.

[15] An EPD is a third-party verified document that reports *environmental* data based on LCA and other relevant information.

[16] An LCI is a list of primary resource input flows and emissions (air, water, land) output flows attributed to an industrial process or group of processes (e.g. a building life cycle)

The assessment draws on the following three LCI data sources:

- The Athena LCI Database, v5.2.0116[17]
- The US LCI Database[18]
- The ecoinvent LCI Database, v3[19]

Environmental data from EPDs were used for the following products:

- Trespa cladding
- Carpet tile
- Resilient flooring
- Ceramic tile flooring
- Acoustic ceiling tile
- Medium density fibreboard

Table 32 presents a summary of data sources used for the various information modules considered in the assessment. In general, the Athena LCI Database is the primary source for process data; this database in turn draws on the US LCI Database for energy combustion and pre-combustion processes, including those related to electricity generation and transportation. The ecoinvent LCI Database was used for processes not available in either Athena or US LCI databases, in particular waste processing and landfill effects. Since ecoinvent data is European in context, the datasets used were adjusted to better reflect a Canadian or British Columbian system boundary context, as outlined in Section 6.2.

6.2 Data Adjustments and Substitutions

In order to improve geographic representativeness and data consistency, the following adjustments were made to ecoinvent LCI Database processes used in the assessment:

- European energy use profiles were substituted with data from the US LCI.
- Material processes were substituted with data from the US LCI, if available.
- Infrastructure effects were removed from the processes to retain consistency with current North American LCA practice.

LCI data for some of the building's materials were unavailable. In order to include these materials in the scope of assessment, materials from the Athena LCI Database deemed to most closely approximate their environmental profile were substituted. In some cases, the resulting estimates required a combination of more than one LCI profile. Some of the substitutions also required scaling the material takeoff to adjust for differences between the products. See Table 33 for a summary of LCI data substitutions.

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[17] http://www.athenasmi.org/our-software-data/lca-databases/
[18] http://www.nrel.gov/lci/
[19] http://www.ecoinvent.ch/

6.3 Data Quality

Precision: all LCI/LCA data sources used were compiled in accordance with ISO 14040/14044 procedures and requirements. The data adjustments and substitutions noted in Section 6.2 introduce inaccuracies.

Completeness: all relevant, specific processes, including inputs (raw materials, energy, water) and outputs (emissions and production volume) are considered and modeled to represent the object of assessment (the building).

Consistency: the assessment draws primarily on a single LCI database (Athena LCI) with consistent system boundary and scope. Ecoinvent processes were adjusted to align with Athena/US LCI Database system boundaries.

Reproducibility: the data used is available in the LCI databases noted; the document specifies the adjustments and substitutions made to data such that they are generally reproducible.

Representativeness:

- Time related coverage-while the most recent validation of some LCI data sets used are beyond the EN 15978 limit of ten years, these processes are of limited significance to the total environmental effects of the whole-building assessment.
- Geographical coverage **-** at minimum North America and representative of the region (Canada, British Columbia) where the building is located.
- Technological coverage - average, reflecting the physical reality of the products found in the building.

7.0 List of Indicators Used for Assessment and Expression of Results

A summary of the environmental indicator results required by EN 15978 is presented in Table 7. Indicators excluded from the assessment were not evaluated because the underlying LCI datasets used do not sufficiently support them.

The environmental impacts considered were evaluated according to the EPA's *Tool for the Reduction and Assessment of Chemical and other environmental Impacts* (TRACI) v2.1 life cycle impact assessment (LCIA)[20] methodology. TRACI provides a North American context for the supported measures, with a result that some of the indicator units are different than those required by EN 15978. This has been deemed acceptable for this assessment since North American adoption of a standard like EN 15978 would presumably be structured on the use of TRACI as LCIA methodology.

[20] **Life cycle impact assessment** (LCIA) is the process of evaluating the environmental effects of an LCI – e.g. evaluating global warming potential from various greenhouse gas emissions

Energy resource use was evaluated according to *Cumulative Energy Demand* (CED) methodology. All other indicators considered were evaluated by summing elementary LCI flows (e.g. net use of fresh water) or intermediate LCI flows (e.g. non-hazardous waste disposed) over the building life cycle.

Table 7: Reported Environmental Indicators

EN 15978 Environmental Indicator	Methodology	Unit
Environmental Impacts		
Global warming potential	TRACI v2.1	kg CO_2 eq.
Depletion of the stratospheric ozone layer	TRACI v2.1	kg CFC-11 eq.
Acidification potential of land and water	TRACI v2.1	kg SO_2 eq.
Eutrophication potential	TRACI v2.1	kg N eq.
Formation potential of tropospheric ozone photochemical oxidants	TRACI v2.1	kg O_3 eq.
Abiotic resource depletion potential for elements	*not in scope*	
Abiotic resource depletion potential of fossil fuels	TRACI v2.1	MJ surplus
Resource Use		
Renewable primary energy excluding energy resources used as raw material	CED	MJ
Renewable primary energy resources used as raw material	CED	MJ
Non-renewable primary energy excluding resources used as raw material	CED	MJ
Non-renewable primary energy resources used as raw material	CED	MJ
Secondary material	Sum of LCI flows	kg
Renewable secondary fuels	*not in scope*	
Non-renewable secondary fuels	*not in scope*	
Net use of fresh water	Sum of LCI flows	m^3
Waste Categories		
Non-hazardous waste disposed	Sum of LCI flows	kg
Hazardous waste disposed[21]	*not in scope*	
Radioactive waste disposed	*not in scope*	
Output Flows Leaving the System		
Components for re-use	Sum of LCI flows	kg
Materials for recycling	Sum of LCI flows	kg
Materials for energy recovery (not being waste incineration)	Sum of LCI flows	kg
Exported energy	Sum of LCI flows	MJ

CED= Cumulative Energy Demand (v1.08)

Please note the following:

- *Net use of fresh water is* a summation of primary fresh water withdrawals, including water consumed and water discharged after withdrawal.
- *Use of secondary material* is a summation of the use of recycled and reused materials in products that make up the building.
- *Non-hazardous waste disposed* is a summation of the final waste flows landfilled and incinerated.

[21] North American LCI datasets generally do not track waste flows by type; a limitation of this study is that some hazardous and radioactive wastes have likely been characterized as non-hazardous.

- *Output Flows Leaving the System* indicators include only flows that are downstream from the building, i.e. they do not include flows leaving the system from the Product Stage (one exception to this is steel waste from fabrication).

8.0 Communication of Assessment Results

This section presents LCA results tables for Tallwood House; please note the following:

- Table entries marked "xx" refer to information modules or environmental indictors that are not included in the study scope.
- As per EN 15978, tabular results for non-building-related operational energy (the end-use "plug loads", reported as module B6b), are disaggregated from building-integrated technical system operational energy results (all other reported end-uses, reported as B6a).
- As a declaration of environmental performance, results synthesis and conclusions regarding the building's level of performance are left to the reader.

8.1 Life Cycle Results

Table 8 presents 100-year total life cycle results for Tallwood House, along with results normalized per-m^2 (gross floor area), per-occupant, per-year, per-m^2-year, and per-occupant-year.

8.2 Contribution Analysis

As required by EN 15978, total life cycle results are presented by information module in Table 9 through Table 11. Figure 6 through Figure 12 in Appendix A graphically present the following contribution analyses:

- Information Module Contributions to Total LCA Results
- Resource Type Contributions to Total LCA Results
- Construction Element Contributions to Material Use LCA Results
- Material Type Contributions to Material Use LCA Results
- End-use Contributions to Operational Energy LCA Results
- Fuel Type Contributions to Operational Energy LCA Results
- Water Flow Type Contributions to Operational Water LCA Results[22]

[22] Water use estimates were not provided by end-use and therefore a graphic showing end-use contributions to environmental impact is not presented available.

8.3 Sensitivity Analysis

EN 15978 requires that “the significance of the influence of the data chosen for the building assessment shall be determined (e.g. through a sensitivity analysis) and reported.” For the most part, the assessment draws on data from a single source (Athena LCI Database), which has a high degree of methodological consistency.

The following three sensitivity analyses were conducted; each aims to explore the sensitivity of aspects whose assumed scenarios, LCI datasets, and/or material quantity calculations could measurably change life cycle results:

- **Scenario 1:** operational energy use estimates are increased by 10%;
- **Scenario 2:** cross laminated timber, glulam, and PSL quantities are increased by 10%;
- **Scenario 3:** concrete and rebar quantities are increased by 10%; and
- **Scenario 4:** the total truck transport distance to site of gypsum board products is increased to 1000 km.

Table 12 presents the ratios of the total life cycle results of these sensitivity cases to the baseline case.

8.4 Additional Results

Table 13 and Table 14 present indicator results for the following additional information outlined in Section 5.0:

- Modules A-C, wood carbon sequestration
- Modules A-C, concrete carbon sequestration
- Module D, steel recycling
- Module D, aluminum recycling
- Module D, concrete recycling
- Module D, concrete recycling carbon sequestration
- Module D, wood product reuse (CLT, glulam and PSL)

Table 8: Tallwood House LCA Results

EN 15978 Environmental Indicator	Unit	Total	Per-m2	Per-occupant	Per-year	Per-m2-year	Per-occupant-year
Environmental Impacts							
Global warming potential	kg CO_2 eq.	2.99E+07	1.98E+03	7.39E+04	2.99E+05	1.98E+01	7.39E+02
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	1.08E-01	7.15E-06	2.68E-04	1.08E-03	7.15E-08	2.68E-06
Acidification potential of land and water	kg SO_2 eq.	1.84E+05	1.22E+01	4.56E+02	1.84E+03	1.22E-01	4.56E+00
Eutrophication potential	kg N eq.	4.30E+04	2.84E+00	1.06E+02	4.30E+02	2.84E-02	1.06E+00
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.50E+06	9.93E+01	3.71E+03	1.50E+04	9.93E-01	3.71E+01
Abiotic resource depletion potential for elements	kg Sb eq.	xx	xx	xx	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	6.59E+07	4.36E+03	1.63E+05	6.59E+05	4.36E+01	1.63E+03
Resource Use							
Renewable primary energy excluding energy resources used as raw material	MJ	7.38E+08	4.88E+04	1.83E+06	7.38E+06	4.88E+02	1.83E+04
Renewable primary energy resources used as raw material	MJ	2.59E+07	1.72E+03	6.42E+04	2.59E+05	1.72E+01	6.42E+02
Non-renewable primary energy excluding resources used as raw material	MJ	4.65E+08	3.08E+04	1.15E+06	4.65E+06	3.08E+02	1.15E+04
Non-renewable primary energy resources used as raw material	MJ	5.72E+06	3.79E+02	1.42E+04	5.72E+04	3.79E+00	1.42E+02
Secondary material	kg	2.23E+06	1.48E+02	5.53E+03	2.23E+04	1.48E+00	5.53E+01
Renewable secondary fuels	MJ	xx	xx	xx	xx	xx	xx
Non-renewable secondary fuels	MJ	xx	xx	xx	xx	xx	xx
Net use of fresh water	m^3	1.33E+06	8.81E+01	3.29E+03	1.33E+04	8.81E-01	3.29E+01
Waste Categories							
Non-hazardous waste disposed	kg	5.65E+06	3.74E+02	1.40E+04	5.65E+04	3.74E+00	1.40E+02
Hazardous waste disposed	kg	xx	xx	xx	xx	xx	xx
Radioactive waste disposed	kg	xx	xx	xx	xx	xx	xx
Output Flows Leaving the System							
Components for re-use	kg	9.72E+05	6.43E+01	2.41E+03	9.72E+03	6.43E-01	2.41E+01
Materials for recycling	kg	8.09E+06	5.35E+02	2.00E+04	8.09E+04	5.35E+00	2.00E+02
Materials for energy recovery (not being waste incineration)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 9: Information Module Contributions to Environmental Impact Indicator Results

EN 15978 Environmental Indicator	Environmental Impacts						
	Global warming potential	Depletion potential of the stratospheric ozone layer	Acidification potential of land and water	Eutrophication potential	Formation potential of troposheric ozone photochemical oxidants	Abiotic resource depletion potential for elements	Abiotic resource depletion potential of fossil fuels
	kg CO2 eq.	kg CFC-11 eq.	moles of H+ eq.	kg N eq.	kg O3 eq.	kg Sb eq.	MJ surplus
A1 Raw Material Supply, A2 Transport, A3 Manufacturing	2.69E+06	2.89E-02	1.44E+04	1.11E+03	2.05E+05	xx	3.08E+06
A4 Transport	1.59E+05	6.00E-06	1.94E+03	1.23E+02	6.40E+04	xx	2.87E+05
A5 Construction Installation Process	1.83E+05	1.58E-03	9.33E+02	7.84E+01	1.91E+04	xx	2.90E+05
B1 Use of Products	xx	xx	xx	xx	xx	xx	xx
B2 Maintenance	3.06E+04	1.28E-04	1.53E+02	5.47E+00	2.53E+03	xx	1.77E+05
B3 Repair	4.80E+05	1.31E-02	3.66E+03	1.66E+02	4.23E+04	xx	6.14E+05
B4 Replacement	1.02E+06	3.45E-02	6.43E+03	4.72E+02	8.12E+04	xx	1.37E+06
B5 Refurbishment	xx	xx	xx	xx	xx	xx	xx
B6a Operational Energy Use, building integrated	2.28E+07	3.50E-04	1.42E+05	2.68E+03	9.34E+05	xx	5.55E+07
B6b Operational Energy Use, plug loads	1.65E+06	5.48E-05	4.86E+03	2.01E+02	7.08E+04	xx	3.25E+06
B7 Operational Water Use	7.03E+05	2.64E-02	8.64E+03	3.81E+04	5.30E+04	xx	9.82E+05
C1 De-construction and Demolition	1.09E+05	4.53E-06	1.31E+02	1.08E+01	3.17E+03	xx	2.16E+05
C2 Transport	5.14E+04	2.03E-06	5.47E+02	3.48E+01	1.79E+04	xx	9.66E+04
C3 Waste Processing	1.71E+04	3.96E-07	1.79E+02	6.80E+00	3.43E+03	xx	3.24E+04
C4 Disposal	1.87E+04	3.03E-03	1.49E+02	2.57E+01	3.87E+03	xx	2.97E+04
Total	**2.99E+07**	**1.08E-01**	**1.84E+05**	**4.30E+04**	**1.50E+06**	**xx**	**6.59E+07**

Table 10: Information Module Contributions to Resource Use Indicator Results

EN 15978 Environmental Indicator	Resource Use							
	Use of renewable primary energy excluding energy used as raw material	Use of renewable primary energy resources used as raw material	Use of non-renewable primary energy excluding energy used as raw material	Use of non-renewable primary energy resources used as raw material	Use of secondary material	Use of renewable secondary fuels	Use of non-renewable secondary fuels	Use of net fresh water
	MJ, net calorific value	MJ, net calorific value	MJ, net calorific value	MJ, net calorific value	kg	MJ	MJ	m3
A1 Raw Material Supply, A2 Transport, A3 Manufacturing	8.89E+06	2.25E+07	3.47E+07	2.10E+06	1.83E+06	xx	xx	2.51E+04
A4 Transport	9.13E+02	0.00E+00	2.04E+06	0.00E+00	0.00E+00	xx	xx	0.00E+00
A5 Construction Installation Process	5.52E+05	3.49E+05	2.36E+06	6.04E+04	9.41E+04	xx	xx	9.60E+02
B1 Use of Products	xx	xx	xx	xx	xx	xx	xx	xx
B2 Maintenance	4.94E+04	0.00E+00	2.14E+05	1.03E+06	0.00E+00	xx	xx	1.30E+01
B3 Repair	9.99E+05	3.08E+05	4.64E+06	6.08E+05	6.05E+04	xx	xx	1.42E+03
B4 Replacement	3.09E+06	2.76E+06	1.43E+07	1.92E+06	2.54E+05	xx	xx	5.37E+03
B5 Refurbishment	xx	xx	xx	xx	xx	xx	xx	xx
B6a Operational Energy Use, building integrated	6.36E+08	0.00E+00	3.68E+08	0.00E+00	0.00E+00	xx	xx	9.95E-04
B6b Operational Energy Use, plug loads	8.75E+07	0.00E+00	2.46E+07	0.00E+00	0.00E+00	xx	xx	1.58E-04
B7 Operational Water Use	4.67E+05	0.00E+00	1.21E+07	0.00E+00	0.00E+00	xx	xx	1.30E+06
C1 De-construction and Demolition	6.58E+02	0.00E+00	1.51E+06	0.00E+00	0.00E+00	xx	xx	0.00E+00
C2 Transport	2.82E+02	0.00E+00	6.84E+05	0.00E+00	0.00E+00	xx	xx	0.00E+00
C3 Waste Processing	2.66E+04	0.00E+00	3.00E+05	0.00E+00	0.00E+00	xx	xx	0.00E+00
C4 Disposal	2.23E+03	0.00E+00	2.46E+05	0.00E+00	0.00E+00	xx	xx	3.12E+00
Total	**7.38E+08**	**2.59E+07**	**4.65E+08**	**5.72E+06**	**2.23E+06**	**xx**	**xx**	**1.33E+06**

Table 11: Information Module Contributions to Waste Category and Output Flow Indicator Results

EN 15978 Environmental Indicator	Waste Categories			Output Flows			
	Non hazardous waste to disposal	Hazardous waste to disposal	Radioactive waste	Components for reuse	Material for recycling	Material for energy recovery	Exported energy
	kg	kg	kg	kg	kg	kg	MJ
A1 Raw Material Supply, A2 Transport, A3 Manufacturing	1.01E+06	xx	xx	0.00E+00	1.58E+03	0.00E+00	0.00E+00
A4 Transport	1.47E+03	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
A5 Construction Installation Process	1.82E+05	xx	xx	8.04E+03	3.69E+05	0.00E+00	0.00E+00
B1 Use of Products	xx	xx	xx	xx	xx	xx	xx
B2 Maintenance	3.99E+04	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B3 Repair	1.56E+05	xx	xx	0.00E+00	2.92E+05	0.00E+00	0.00E+00
B4 Replacement	6.82E+05	xx	xx	0.00E+00	5.60E+05	0.00E+00	0.00E+00
B5 Refurbishment	xx	xx	xx	xx	xx	xx	xx
B6a Operational Energy Use, building integrated	5.98E+05	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B6b Operational Energy Use, plug loads	1.78E+04	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B7 Operational Water Use	1.17E+04	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1 De-construction and Demolition	1.19E+03	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C2 Transport	4.55E+02	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C3 Waste Processing	1.10E+02	xx	xx	9.64E+05	6.86E+06	0.00E+00	0.00E+00
C4 Disposal	2.95E+06	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	**5.65E+06**	**xx**	**xx**	**9.72E+05**	**8.09E+06**	**0.00E+00**	**0.00E+00**

Table 12: Sensitivity Analysis Results

EN 15978 Environmental Indicator	Unit	Scenario 1: 10% increase in operating energy use	Scenario 2: 10% increase in CLT, glulam & PSL	Scenario 3: 10% increase in ready-mix concrete & rebar	Scenario 4: gypsum transport 1000 km
Environmental Impacts					
Global warming potential	kg CO_2 eq.	1.082	1.001	1.005	1.004
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	1.000	1.001	1.013	1.000
Acidification potential of land and water	kg SO_2 eq.	1.080	1.001	1.003	1.006
Eutrophication potential	kg N eq.	1.007	1.000	1.001	1.002
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.067	1.004	1.007	1.026
Abiotic resource depletion potential for elements	kg Sb eq.	xx	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	1.089	1.001	1.002	1.003
Resource Use					
Renewable primary energy excluding energy resources used as raw material	MJ	1.098	1.001	1.000	1.000
Renewable primary energy resources used as raw material	MJ	1.000	1.078	1.000	1.000
Non-renewable primary energy excluding resources used as raw material	MJ	1.084	1.001	1.003	1.003
Non-renewable primary energy resources used as raw material	MJ	1.000	1.011	1.000	1.000
Secondary material	kg	1.000	1.000	1.052	1.000
Renewable secondary fuels	MJ	xx	xx	xx	xx
Non-renewable secondary fuels	MJ	xx	xx	xx	xx
Net use of fresh water	m^3	1.000	1.000	1.001	1.000
Waste Categories					
Non-hazardous waste disposed	kg	1.011	1.003	1.059	1.000
Hazardous waste disposed	kg	xx	xx	xx	xx
Radioactive waste disposed	kg	xx	xx	xx	xx
Output Flows Leaving the System					
Components for re-use	kg	1.000	1.084	1.000	1.000
Materials for recycling	kg	1.000	1.000	1.073	1.000
Materials for energy recovery (not being waste incineration)	kg	n/a	n/a	n/a	n/a
Exported energy	MJ	n/a	n/a	n/a	n/a

Note: values presented in this table are the total life cycle sensitivity scenario results divided by the baseline results

Table 13: Additional Information Results, modules A-C

EN 15978 Environmental Indicator	Unit	Wood carbon sequest.	Concrete carbon sequest.
Environmental Impacts			
Global warming potential	kg CO_2 eq.	-4.80E+05	-1.80E+05
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	0.00E+00	0.00E+00
Acidification potential of land and water	kg SO_2 eq.	0.00E+00	0.00E+00
Eutrophication potential	kg N eq.	0.00E+00	0.00E+00
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	0.00E+00	0.00E+00
Abiotic resource depletion potential for elements	kg Sb eq.	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	0.00E+00	0.00E+00
Resource Use			
Renewable primary energy excluding energy resources used as raw material	MJ	0.00E+00	0.00E+00
Renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00
Non-renewable primary energy excluding resources used as raw material	MJ	0.00E+00	0.00E+00
Non-renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00
Secondary material	kg	0.00E+00	0.00E+00
Renewable secondary fuels	MJ	xx	xx
Non-renewable secondary fuels	MJ	xx	xx
Net use of fresh water	m^3	0.00E+00	0.00E+00
Waste Categories			
Non-hazardous waste disposed	kg	0.00E+00	0.00E+00
Hazardous waste disposed	kg	xx	xx
Radioactive waste disposed	kg	xx	xx
Output Flows Leaving the System			
Components for re-use	kg	0.00E+00	0.00E+00
Materials for recycling	kg	0.00E+00	0.00E+00
Materials for energy recovery (not being waste incineration)	kg	0.00E+00	0.00E+00
Exported energy	MJ	0.00E+00	0.00E+00

Note: a negative value means a sequestration or avoided impact

Table 14: Additional Information Results, module D

EN 15978 Environmental Indicator	Unit	Steel recycling	Aluminum recycling	Concrete recycling	Recycled concrete carbon sequest.	Wood product reuse
Environmental Impacts						
Global warming potential	kg CO_2 eq.	5.23E+04	-1.91E+05	-1.77E+04	-1.57E+05	-1.87E+05
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	0.00E+00	-9.15E-06	-4.72E-07	0.00E+00	-4.81E-04
Acidification potential of land and water	kg SO_2 eq.	1.20E+02	-1.35E+03	-2.00E+02	0.00E+00	-1.51E+03
Eutrophication potential	kg N eq.	2.08E+00	-2.08E+01	-8.75E+00	0.00E+00	-9.98E+01
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.17E+03	-1.04E+04	-4.50E+03	0.00E+00	-3.77E+04
Abiotic resource depletion potential for elements	kg Sb eq.	xx	xx	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	4.29E+02	-1.25E+05	-3.36E+04	0.00E+00	-3.48E+05
Resource Use						
Renewable primary energy excluding energy resources used as raw material	MJ	0.00E+00	-1.21E+06	-2.18E+04	0.00E+00	-4.69E+06
Renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.44E+07
Non-renewable primary energy excluding resources used as raw material	MJ	2.97E+05	-1.93E+06	-2.98E+05	0.00E+00	-2.62E+06
Non-renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.15E+05
Secondary material	kg	3.45E+04	-2.78E+04	-5.79E+06	0.00E+00	-8.12E+05
Renewable secondary fuels	MJ	xx	xx	xx	xx	xx
Non-renewable secondary fuels	MJ	xx	xx	xx	xx	xx
Net use of fresh water	m^3	0.00E+00	-1.38E+03	0.00E+00	0.00E+00	-4.10E+02
Waste Categories						
Non-hazardous waste disposed	kg	-1.30E+03	-7.92E+04	-8.99E+01	0.00E+00	-9.67E+03
Hazardous waste disposed	kg	xx	xx	xx	xx	xx
Radioactive waste disposed	kg	xx	xx	xx	xx	xx
Output Flows Leaving the System						
Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for energy recovery (not being waste incineration)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Note: a negative value means a sequestration or avoided impact

Appendix A: Contribution Analysis Charts

Please note that some of the indicator names in this Appendix have been modified for conciseness.

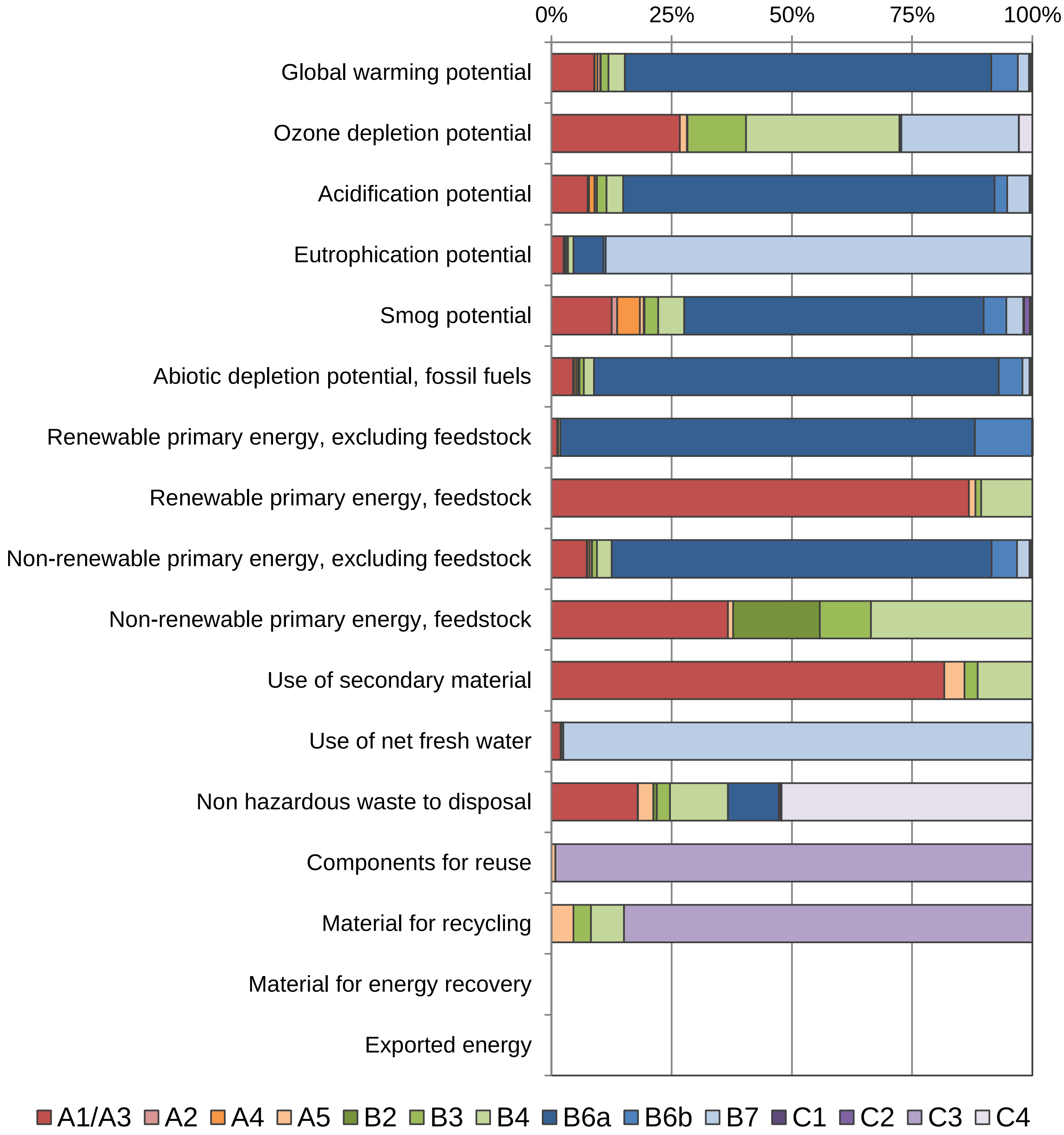

Figure 6: Information Module Contributions to Total LCA Results

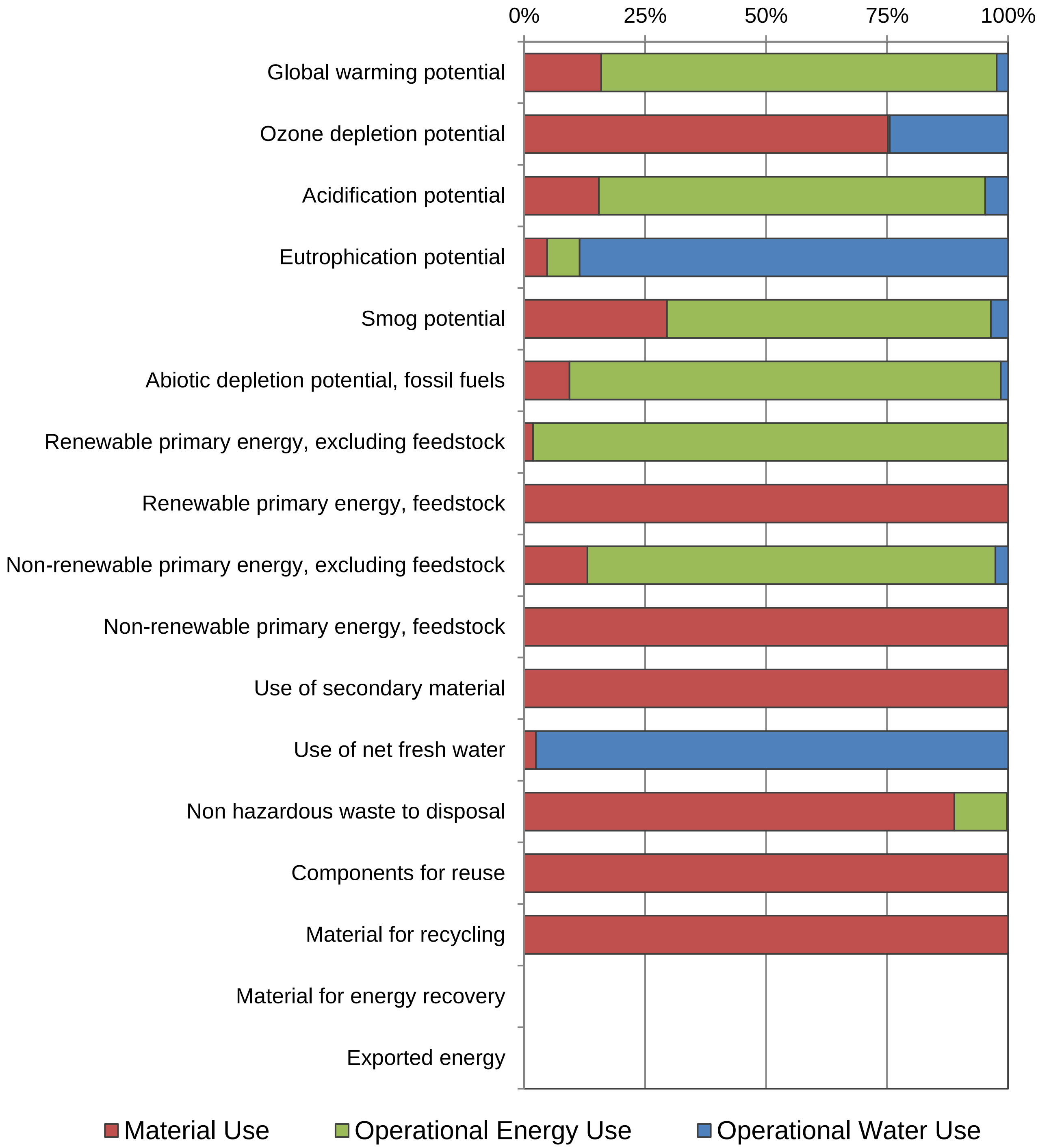

Figure 7: Resource Type Contributions to Total LCA Results

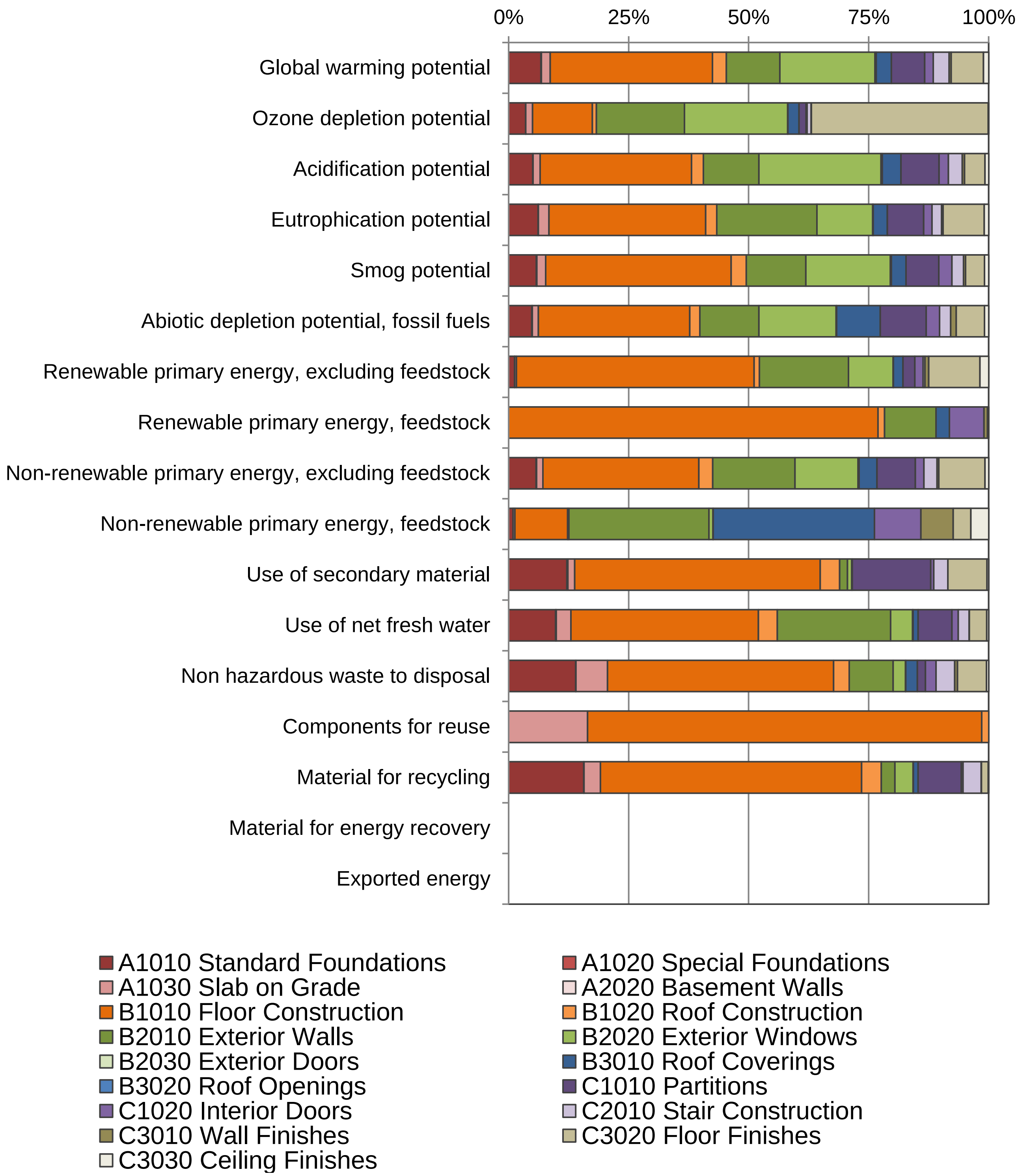

Figure 8: Construction Element Contributions to Material Use LCA Results

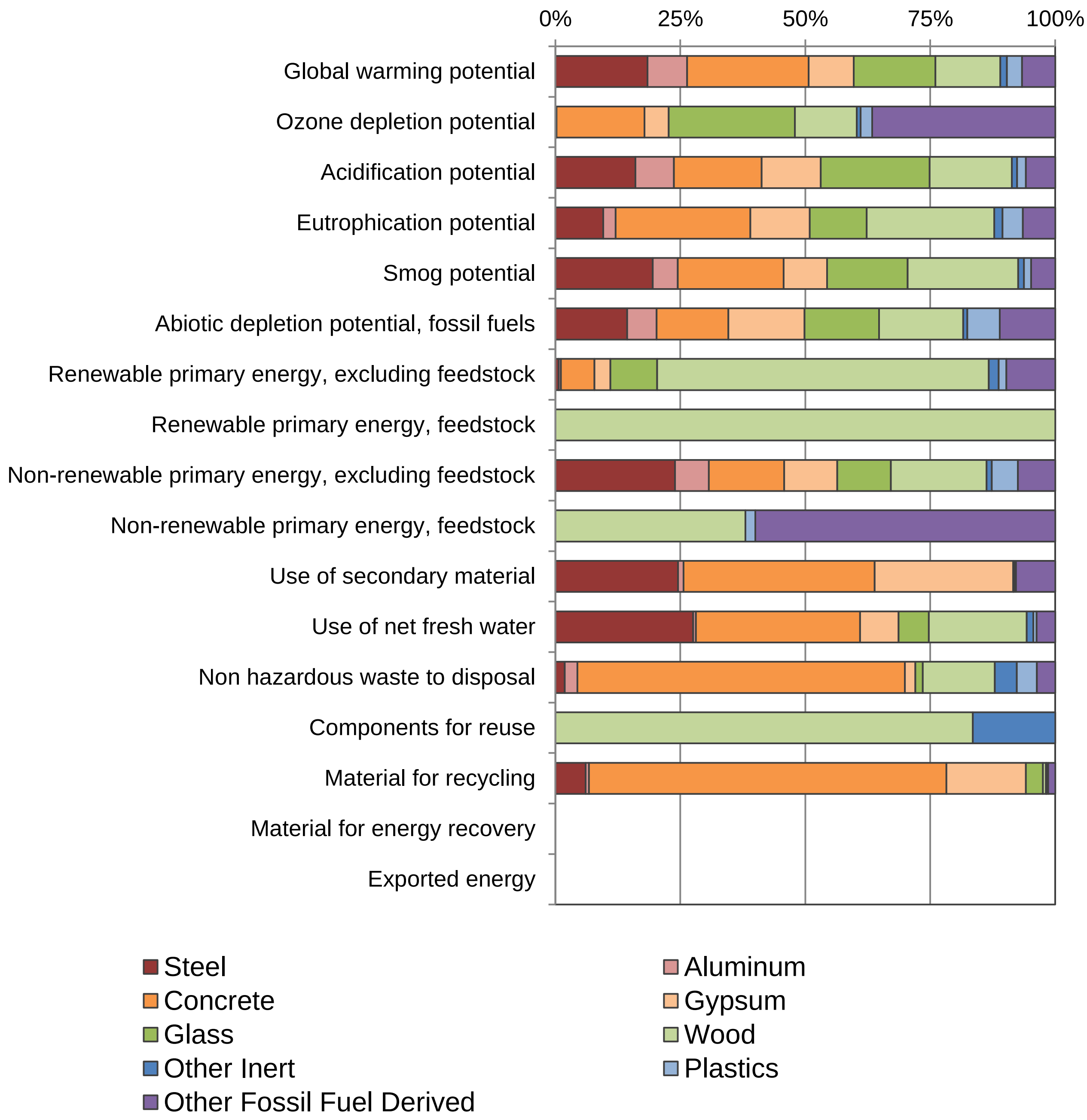

Figure 9: Material Type[23] Contributions to Material Use LCA Results

[23] The various “material types” noted in Figure 9 include building products that are primarily composed of that material. For example, Glass includes flat glass, along with glass fibre and fiberglass batt insulation. Other Inert includes products such as aggregate, brick, and natural stone cladding. Plastics includes polyvinyl chloride, polyethylene, polystyrene, polyisocyanurate, and polypropylene, whereas Other Fossil Fuel includes paint, and rubber- and bitumen-based products.

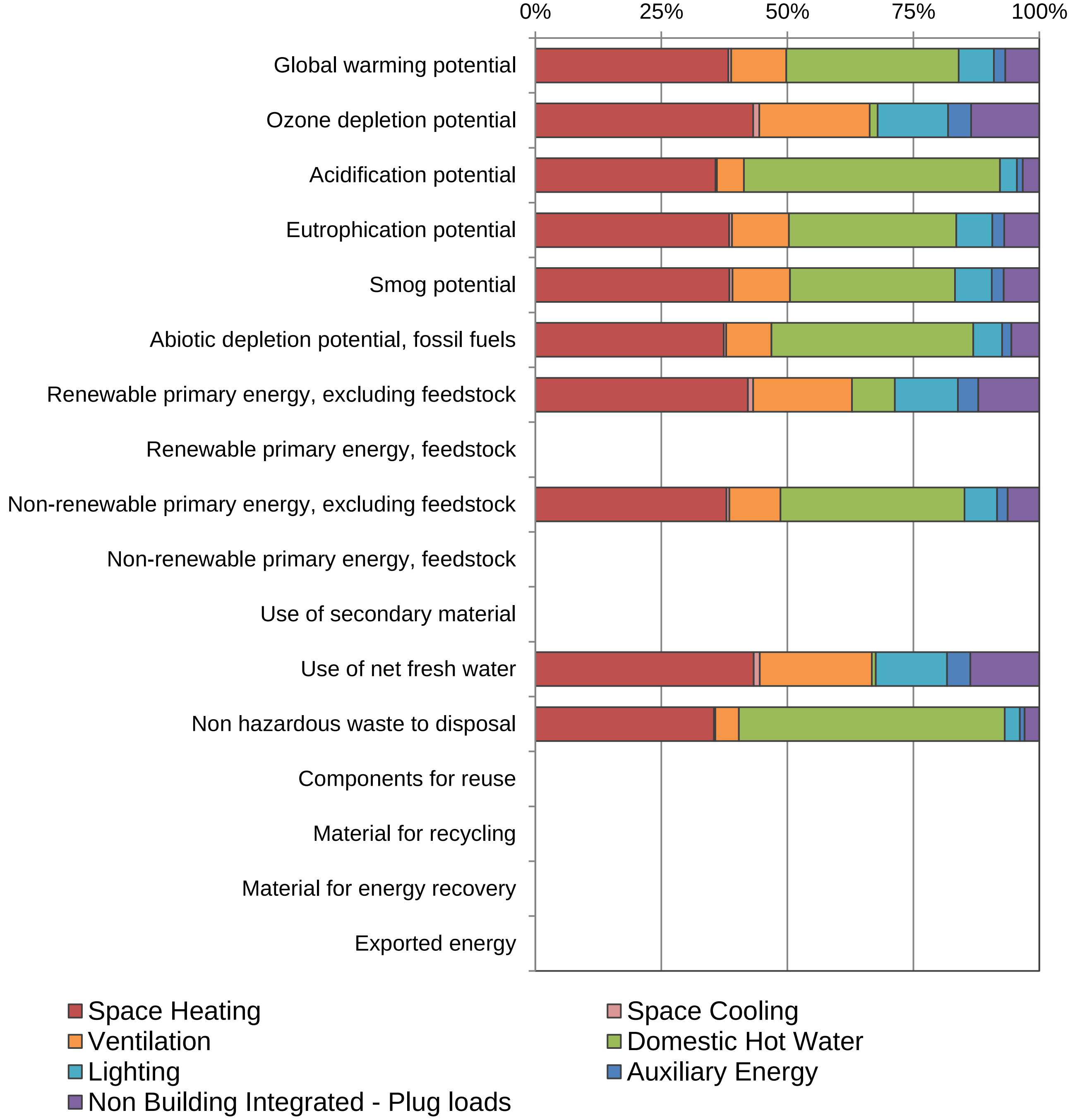

Figure 10: End-use Contributions to Operational Energy LCA Results

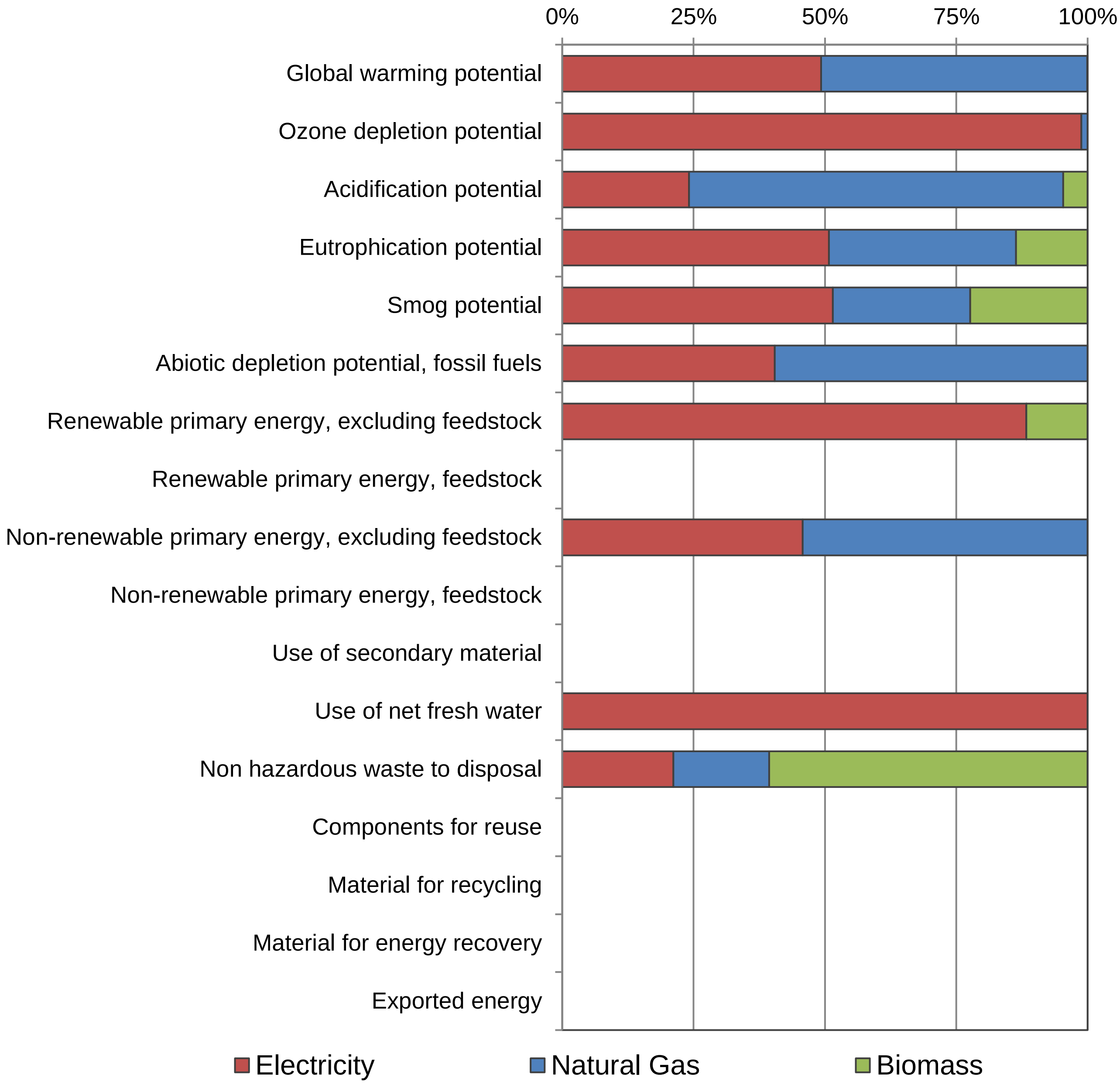

Figure 11: Fuel Type Contributions to Operational Energy LCA Results

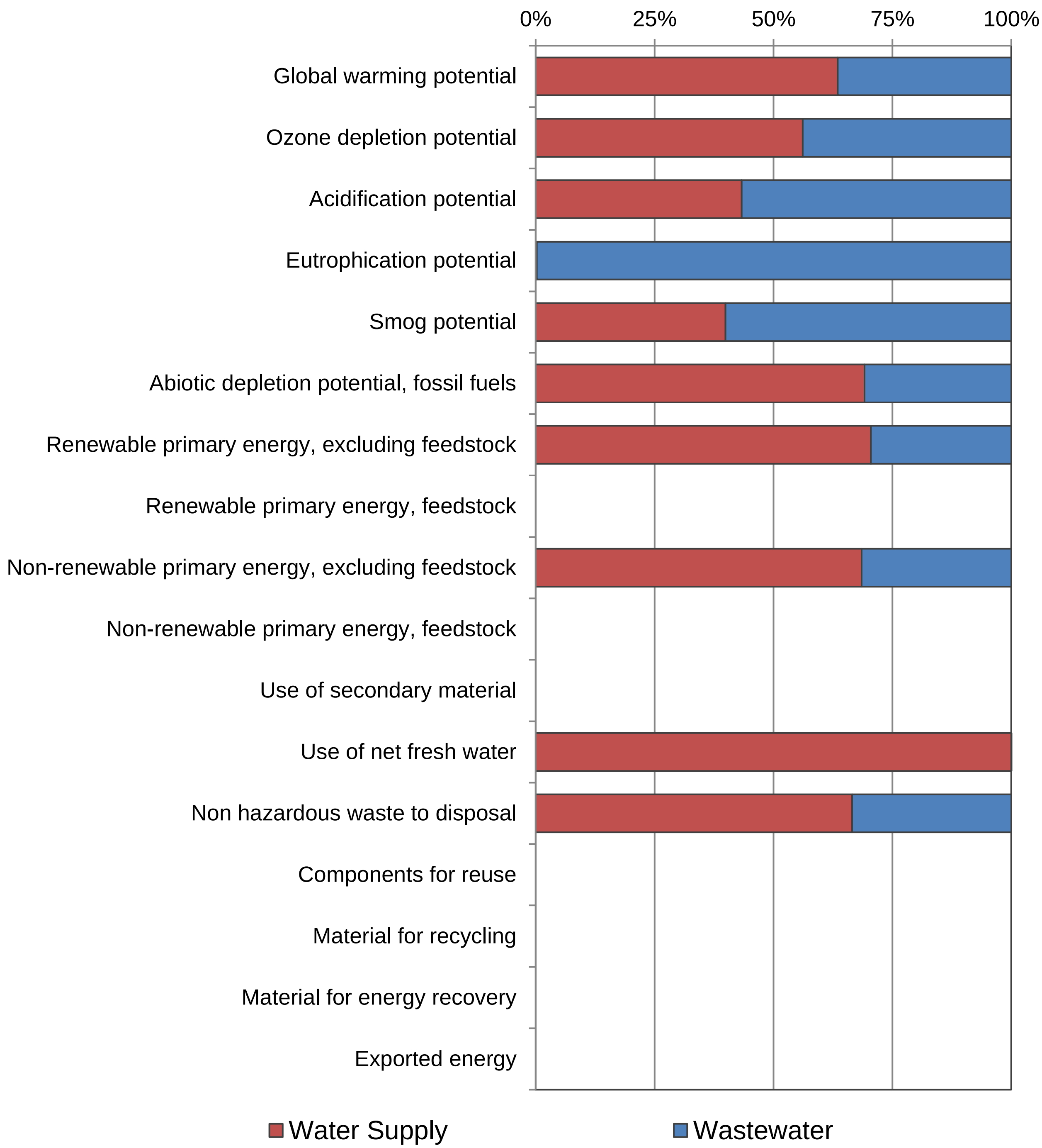

Figure 12: Water Flow Type Contributions to Operational Energy LCA Results

Appendix B: Building Element Design Summary

Table 15: Building Element Design Summary

Element	Design Summary
A1010 Standard Foundations	• 250 reinforced concrete walls • 190 reinforced concrete masonry unit walls • 2800x700x2800 reinforced concrete pad footings • 250-300 deep reinforced concrete strip footings • 1600 deep raft footings
A1020 Special Foundations	• 64 dia. soil anchor tension rods
A1030 Slab on Grade	• 125 reinforced concrete slab with 10 mil polyethylene
A2010 Basement Excavation	*Not included in scope*
A2020 Basement Walls	*No basement walls*
B1010 Floor Construction	• Columns: 500x500, 350x800 reinforced concrete (level 1); 265x265 and 265x215 glulam; 265x265 parallel strand lumber (levels 2-17) • Floor: 600 reinforced concrete slab (level 2); 169 CLT with 40 concrete topping, gypsum board (levels 3-17) • Stair/elevator core walls: 450 reinforced concrete (levels 1-17)
B1020 Roof Construction	• Columns: 265x265 and 265x215 glulam (level 18) • Beams: 125, 150, 250 deep W, C, WT structural steel framing • Roof: 115 deep metal deck (18 ga) • Stair/elevator core walls: 450 reinforced concrete (level 18-roof) • 100 deep concrete mech. pads • 99 CLT canopy (level 2)
B2010 Exterior Walls	• Prefabricated panel: Trespa cladding, 25 deep girts, 50 semi-rigid insulation, liquid-applied vapour permeable membrane, 13 exterior sheathing board, 152 steel stud wall, fibreglass batt cavity insulation, vapor barrier, 16 gypsum board • Exterior site-installed cladding: Trespa cladding, 25 deep girts, 75 semi-rigid, air/vapour barrier, concrete core or CMU backup wall
B2020 Exterior Windows	• Aluminum framed curtain wall (level 1), aluminum framed punched windows (levels 2-18)
B2030 Exterior Doors	• Curtain wall, steel overhead rolling, insulated hollow metal, aluminum doors
B3010 Roof Coverings	• Main roof: 2 ply SBS membrane, asphalt overlay board, 50 stonewool insulation, 64mm polyiso insulation (+ slope), 1 ply SBS membrane vapour barrier, 12 underlay board • Canopy (level 2): standing seam metal roofing system, ventilation / drainage mat, self adhered membrane, polyurethane wood finish
B3020 Roof Openings	*No skylights*
C1010 Partitions	• Light gauge steel stud walls @400 (65, 90, 150, 200 deep), fibreglass insulation (not all assemblies), gypsum board (12, 16, or 25 liner panel for shaft walls) • 190 concrete masonry unit walls
C1020 Interior Doors	• Hollow metal, solid wood, aluminum doors
C1030 Fittings	*Not included in scope*
C2010 Stair Construction	• Reinforced concrete stairs, aluminum rails/balustrades
C2020 Stair Finishes	*No stair finishes*

Element	Design Summary
C3010 Wall Finishes	• Paint (on gypsum board), wood veneer panels, wood grille panels, ceramic tile
C3020 Floor Finishes	• Carpet tile, resilient flooring, ceramic tile, epoxy paint (on concrete)
C3030 Ceiling Finishes	• Paint (on gypsum board), suspended acoustic t-bar system, acoustic wood slat system, wood veneer panels

Table Notes:
1) all dimensions given in mm;
2) for conciseness, not all assembly/assembly components are listed;

Appendix C: Whole-building Bill of Materials

Table 16: Whole-building Bill of Materials

Material	Quantity	Unit
1/2" Moisture Resistant Gypsum Board	756.200	m2
1/2" Regular Gypsum Board	17849.188	m2
1/2" Glass Mat Gypsum Panel	4795.080	m2
5/8" Fire-Rated Type X Gypsum Board	54882.843	m2
5/8" Moisture Resistant Gypsum Board	12009.072	m2
5/8" Regular Gypsum Board	4203.956	m2
6 mil Polyethylene	6276.440	m2
8" Normal Weight Concrete Block	5723.323	Blocks
8mm Trespa Panels	5698.465	m2
Aluminum Cold Rolled Sheet	0.235	Tonnes
Aluminum Extrusion	11.866	Tonnes
Aluminum Window Frame	4316.992	kg
Bolts, Fasteners, Clips	0.313	tonnes
Carpet Tile, Interface Common Theme	5099.560	m2
Carpet Tile, Interface Ground Waves	78.330	m2
Carpet Tile, Interface Verticals	285.988	m2
Ceiling Tile	1351.370	m2
Ceramic tile flooring	126.208	m2
Coarse Aggregate Crushed Stone	319.974	tonnes
Concrete Benchmark 5000 psi 30% FA	574.270	m3
Concrete Benchmark 5000 psi 50% FA	2637.424	m3
Cross Laminated Timber	1935.433	m3
Double Glazed Soft Coated Air	1616.972	m2
EPDM membrane (black, 60 mil)	96.464	kg
Expanded Polystyrene	25.779	m2 (25mm)
Extruded Polystyrene	433.370	m2 (25mm)
FG Batt R11-15	103179.039	m2 (25mm)
FG Batt R20	28770.480	m2 (25mm)
Galvanized Decking	12.026	tonnes
Galvanized Sheet	11.273	tonnes
Galvanized Studs	83.223	tonnes
Glazing Panel	21.133	tonnes

Material	Quantity	Unit
GluLam Sections	200.706	m3
Hollow Structural Steel	0.228	tonnes
Joint Compound	44.638	tonnes
MBS Metal Roof Cladding - Commercial (26 Ga.)	201.450	m2
Medium Density Fibreboard	7.745	m2
Modified Bitumen membrane	8540.547	kg
Mortar	21.682	m3
MW Batt R11-15	1608.017	m2 (25mm)
Nails	2.962	tonnes
Oriented Strand Board	954.480	m2 (9mm)
Paper Tape	0.539	tonnes
Parallel Strand Lumber	9.306	m3
Polyiso Foam Board (unfaced)	2783.900	m2 (25mm)
Rebar, Rod, Light Sections	263.042	tonnes
Resilient flooring	4129.576	m2
Roofing Asphalt	604.983	kg
Screws Nuts & Bolts	5.403	tonnes
Small Dimension Softwood Lumber, kiln-dried	104.393	m3
Solvent Based Alkyd Paint	724.581	L
Solvent Based Varnish	163.577	L
Steel Plate	68.287	tonnes
VR 1/2" Drainage Mat	201.450	m2
VR 20 mil Root Barrier	416.685	m2
Water Based Latex Paint	14084.247	L
Wide Flange Sections	101.550	tonnes
Wire Rod	4.403	tonnes

Please note that the reported quantities are those required by the building at initial construction and do not include wastage.

Appendix D: Scenario Tables

Please note that the table captions include references to the relevant information modules.

Table 17: Scenarios – Transport of Materials to Site (modules A4, B2, B3, B4)

Material/Assembly	Road Short Haul, diesel (km)	Road Long Haul, diesel (km)	Rail, diesel (km)	Barge, residual fuel oil (km)	Ocean, residual fuel oil (km)
1/2" Moisture Resistant Gypsum Board	130				
1/2" Regular Gypsum Board	130				
1/2" Glass Mat Gypsum Panel	130				
5/8" Fire-Rated Type X Gypsum Board	130				
5/8" Moisture Resistant Gypsum Board	130				
5/8" Regular Gypsum Board	130				
6 mil Polyethylene	55		4,137		

Material/Assembly	Road Short Haul, diesel (km)	Road Long Haul, diesel (km)	Rail, diesel (km)	Barge, residual fuel oil (km)	Ocean, residual fuel oil (km)
8" Normal Weight Concrete Block	60				
8mm Trespa Panels	175				16,462
Aluminum Cold Rolled Sheet		1,710			
Aluminum Extrusion	35.6	2,103			
Aluminum Window Frame	35.6	2,103			
Bolts, Fasteners, Clips	60				
Carpet Tile, Interface Common Theme		805			
Carpet Tile, Interface Ground Waves		805			
Carpet Tile, Interface Verticals		805			
Ceiling Tile		478			
Ceramic tile flooring		805			
Coarse Aggregate Crushed Stone	60				
Concrete Benchmark 5000 psi 30% FA	16				
Concrete Benchmark 5000 psi 50% FA	16				
Cross Laminated Timber		413			
Double Glazed Soft Coated Air		500			
EPDM membrane (black, 60 mil)		4,330			
Expanded Polystyrene	100				
Extruded Polystyrene	100	1,211			
FG Batt R11-15	100	1,180			
FG Batt R20	100	1,180			
Galvanized Decking	25		4,137		
Galvanized Sheet	25		4,137		
Galvanized Studs	25		4,137		
Glazing Panel		500			
GluLam Sections		413			
Hollow Structural Steel	25		4,137		
Joint Compound		531			
MBS Metal Roof Cladding - Commercial (26 Ga.)	25		4,137		
Medium Density Fibreboard	55				
Modified Bitumen membrane	170	390			
Mortar	60				
MW Batt R11-15	104	511			
Nails	60				
Oriented Strand Board		337			
Paper Tape	130	412			
Parallel Strand Lumber	55				
Polyiso Foam Board (unfaced)		3,298			
Rebar, Rod, Light Sections	60				
Resilient flooring		805			
Roofing Asphalt	60				
Screws Nuts & Bolts	60				
Small Dimension Softwood Lumber, kiln-dried		337			

Material/Assembly	Road Short Haul, diesel (km)	Road Long Haul, diesel (km)	Rail, diesel (km)	Barge, residual fuel oil (km)	Ocean, residual fuel oil (km)
Solvent Based Alkyd Paint	90				
Solvent Based Varnish	90				
Steel Plate	33		3,164		
VR 1/2" Drainage Mat		300			
VR 20 mil Root Barrier		300			
Water Based Latex Paint	90				
Wide Flange Sections	25		4,137		
Wire Rod	33		3,164		

Table 18: Scenarios – Construction Energy Use (modules A5, B2, B3, B4)

Module	Diesel (L)	Gasoline (L)	Electricity (kWh)
A5	15,155	519	94,057
B2	991	0	0
B3	816	0	0
B4	1,943	0	0

Table 19: Scenarios – Construction Material Wastage (modules A5, B2, B3, B4)

Material/Assembly	Construction Waste Factor
1/2" Moisture Resistant Gypsum Board	1.100
1/2" Regular Gypsum Board	1.100
1/2" Glass Mat Gypsum Panel	1.100
5/8" Fire-Rated Type X Gypsum Board	1.100
5/8" Moisture Resistant Gypsum Board	1.100
5/8" Regular Gypsum Board	1.100
6 mil Polyethylene	1.020
8" Normal Weight Concrete Block	1.050
8mm Trespa Panels	1.050
Aluminum Cold Rolled Sheet	1.010
Aluminum Extrusion	1.010
Aluminum Window Frame	1.000
Bolts, Fasteners, Clips	1.030
Carpet Tile, Interface Common Theme	1.050
Carpet Tile, Interface Ground Waves	1.050
Carpet Tile, Interface Verticals	1.050

Material/Assembly	Construction Waste Factor
Ceiling Tile	1.050
Ceramic tile flooring	1.050
Coarse Aggregate Crushed Stone	1.000
Concrete Benchmark 5000 psi 30% FA	1.050
Concrete Benchmark 5000 psi 50% FA	1.050
Cross Laminated Timber	1.010
Double Glazed Soft Coated Air	1.000
EPDM membrane (black, 60 mil)	1.030
Expanded Polystyrene	1.050
Extruded Polystyrene	1.050
FG Batt R11-15	1.050
FG Batt R20	1.050
Galvanized Decking	1.010
Galvanized Sheet	1.010
Galvanized Studs	1.010
Glazing Panel	1.000
GluLam Sections	1.010
Hollow Structural Steel	1.010
Joint Compound	1.070
MBS Metal Roof Cladding - Commercial (26 Ga.)	1.010
Medium Density Fibreboard	1.050
Modified Bitumen membrane	1.030
Mortar	1.150
MW Batt R11-15	1.050
Nails	1.030
Oriented Strand Board	1.050
Paper Tape	1.050
Parallel Strand Lumber	1.010
Polyiso Foam Board (unfaced)	1.050
Rebar, Rod, Light Sections	1.010
Resilient flooring	1.050
Roofing Asphalt	1.000
Screws Nuts & Bolts	1.030
Small Dimension Softwood Lumber, kiln-dried	1.080
Solvent Based Alkyd Paint	1.020
Solvent Based Varnish	1.020
Steel Plate	1.010
VR 1/2" Drainage Mat	1.020

Material/Assembly	Construction Waste Factor
VR 20 mil Root Barrier	1.020
Water Based Latex Paint	1.020
Wide Flange Sections	1.010
Wire Rod	1.010

Table 20: Scenarios – Maintenance (module B2)

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Source[a]
Exterior hollow metal doors	Solvent Based Alkyd Paint	10	100	1
Interior hollow metal doors	Solvent Based Alkyd Paint	4	100	1
Interior hollow wood doors	Water Based Latex Paint	4	100	1
Interior solid wood doors	Water Based Latex Paint	4	100	1
CLT canopy	Solvent Based Varnish	10	100	1
Painted gypsum board	Water Based Latex Paint	10	50[b]	1

[a] 1 = Whitestone Maintenance and Repair Cost Reference 2013-2014

[b] 50% replacement because initial quantity assumes two coats, whereas repainting assumes one coat

Table 21: Scenarios – Repair (module B3)

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Source[a]
Slab on grade	Concrete Benchmark 5000 psi 30% FA	15	2	1
	Rebar, Rod, Light Sections	15	2	1
	6 mil Polyethylene	15	2	1
Gypsum Board	1/2" Regular Gypsum Board	20	2	1
	5/8" Fire-Rated Type X Gypsum Board	20	2	1
	5/8" Regular Gypsum Board	20	2	1
	Joint Compound	20	2	1
	Paper Tape	20	2	1
Trespa cladding	8mm Trespa Panels	20	2	1
Windows	Double Glazed Soft Coated Air	1	3.0	3
Curtain wall	EPDM membrane	1	3.0	3
	Glazing Panel	1	3.0	3
	Screws Nuts & Bolts	1	3.0	3
Roof covering	Modified Bitumen membrane	1	1.5	3
	Oriented Strand Board	1	1.5	3
	Roofing Asphalt	1	1.5	3
	MW Batt R11-15	1	1.5	3

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Source[a]
	Polyiso Foam Board (unfaced)	1	1.5	3
	1/2" Moisture Resistant Gypsum Board	1	1.5	3
Exterior aluminum and glass doors	Aluminum Extrusion	12	12	1
	Glazing Panel	12	12	1
	Nails	12	12	1
Exterior steel doors	Galvanized Sheet	17	15	1
	Solvent Based Alkyd Paint	17	15	1
	Expanded Polystyrene	17	15	1
	Nails	17	15	1
Stairs	Concrete Benchmark 5000 psi 50% FA	20	8.5	1
	Rebar, Rod, Light Sections	20	8.5	1
	Aluminum Extrusion	15	20	1
	Aluminum Cold Rolled Sheet	15	20	1
	Bolts, Fasteners, Clips	15	20	1
Wall finishes	Medium Density Fibreboard Small Dimension Softwood Lumber, kiln-dried	10 10	2 2	1 1
	Ceramic tile	10	2	1
Floor finishes	Carpet Tile, Interface Verticals	2	2	1
	Carpet Tile, Interface Common Theme	2	2	1
	Carpet Tile, Interface Verticals	2	2	1
	Resilient flooring	9	2	1
	Ceramic tile flooring	15	2	1
	Solvent Based Alkyd Paint	15	2	1
Ceiling finishes	Ceiling Tile	9	2	1
	Galvanized Sheet	9	2	1
	Small Dimension Softwood Lumber, kiln-dried	10	2	1
	MW Batt R11-15	10	2	1
	Medium Density Fibreboard	10	2	1

[a] 1 = Whitestone Maintenance and Repair Cost Reference 2013-2014, 3 = Athena report *Maintenance, Repair and Replacement Effects for Building Envelope Materials* (2002)

Table 22: Scenarios – Replacement (module B4)

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)[a]	Material Use % ($P_{x,y}$)	Source[b]
Slab on grade	Concrete Benchmark 5000 psi 30% FA	75	100	1
	Rebar, Rod, Light Sections	75	100	1
	6 mil Polyethylene	75	100	1
Gypsum Board	1/2" Regular Gypsum Board	75	100	1
	5/8" Fire-Rated Type X Gypsum Board	75	100	1
	5/8" Regular Gypsum Board	75	100	1
	Joint Compound	75	100	1
	Paper Tape	75	100	1
	Nails	75	100	1

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)[a]	Material Use % ($P_{x,y}$)	Source[b]
Trespa cladding	8mm Trespa Panels	50	100	4
Windows	Double Glazed Soft Coated Air	30	100	2
	Aluminum Window Frame	25	100	2
Curtain wall	Glazing panel	35	100	3
	EPDM membrane	35	100	3
	Glazing Panel	35	100	3
	Screws Nuts & Bolts	35	100	3
Roof covering	Modified Bitumen membrane	20	80	3
	Oriented Strand Board	20	100	3
	Roofing Asphalt	20	100	3
	MW Batt R11-15	20	80	3
	Polyiso Foam Board (unfaced)	20	80	3
	1/2" Moisture Resistant Gypsum Board	20	100	3
	MBS Metal Roof Cladding - Commercial (26 Ga.)	20	100	3
	VR 1/2" Drainage Mat (m2)	20	100	3
Ext. aluminum/glass doors	Aluminum Extrusion	50	100	1
	Glazing Panel	50	100	1
	Nails	50	100	1
Ext. steel doors	Galvanized Sheet	75	100	1
	Solvent Based Alkyd Paint	75	100	1
	Expanded Polystyrene	75	100	1
	Nails	75	100	1
Int. hollow metal doors	Galvanized Sheet (Tonnes)	75	100	1
	Solvent Based Alkyd Paint (L)	75	100	1
	Nails (Tonnes)	75	100	1
Int. aluminum/glass doors	Aluminum Extrusion	50	100	1
	Glazing Panel	50	100	1
	Nails	50	100	1
Int. solid wood doors	Small Dimension Softwood Lumber, kiln-dried (m3)	50	100	1
	Nails (Tonnes)	50	100	1
	Water Based Latex Paint (L)	50	100	1
Stairs	Concrete Benchmark 5000 psi 50% FA	75	100	1
	Rebar, Rod, Light Sections	75	100	1
	Aluminum Extrusion	50	100	1
	Aluminum Cold Rolled Sheet	50	100	1
	Bolts, Fasteners, Clips	50	100	1
Wall finishes	Medium Density Fibreboard	75	100	1
	Small Dimension Softwood Lumber, kiln-dried	75	100	1
	Ceramic tile flooring	75	100	1
Floor finishes	Carpet Tile, Interface Verticals	15	100	4
	Carpet Tile, Interface Common Theme	15	100	4
	Carpet Tile, Interface Verticals	15	100	4
	Resilient flooring	35	100	4
	Ceramic tile flooring	50	100	4
	Solvent Based Alkyd Paint	75	100	1
Ceiling finishes	Ceiling Tile	70	100	4

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)[a]	Material Use % ($P_{x,y}$)	Source[b]
	Galvanized Sheet	70	100	4
	Small Dimension Softwood Lumber, kiln-dried	75	100	1
	MW Batt R11-15	75	100	1
	Medium Density Fibreboard	75	100	1

[a] Please note that materials with task frequencies in excess of the reference study period are not replaced

[b] 1 = Whitestone Maintenance and Repair Cost Reference 2013-2014, 2 = Athena IE4B Database, 3 = Athena report *Maintenance, Repair and Replacement Effects for Building Envelope Materials* (2002), 4 = product EPD

Table 23: Scenarios – Annual Operational Energy Use (module B6)

Energy[a] Type	Quantity	Unit
Natural Gas	50,777	m^3
Electricity	1,798,522	kWh
Biomass	40,464	kg

[a] The energy use presented is the net grid-supplied consumption, i.e. fuels consumed at the district plant and on-site electricity use.

Table 24: Scenarios – Annual Operational Water Use (module B7)

Water Flow Type	Quantity (m^3)
From Municipal Water Supply	12,981
To Municipal Wastewater	12,981

Table 25: Scenarios – Demolition Energy Use (modules B2, B3, B4, C1)

Module	Diesel (L)
B2	0
B3	399
B4	1,766
C1	35,847

Table 26: Scenarios – Waste Outcomes (modules A5, B2, B3, B4, C3, C4)

Waste Type	To Reuse	To Recycling	To Energy Recovery	To Landfill	To Inciner-ation	Source[a]
Steel - rebar & fasteners		70%		30%		1
Steel - all other steel products		98%		2%		1
Aluminum products		95%		5%		1
Concrete products		70%		30%		2
Wood products - CLT, glulam, LVL, PSL	80%	2%		16%	2%	3
Other wood products		10%		80%	10%	1
Aggregate[b]	50%					1
Gypsum products		95%		5%		2
Glass products		95%		5%		2
Insulation products		20%		80%		2
All other materials		50%		50%		2

[a] 1 = default values from IE4B waste outcome database; 2 = based on communication with landfill operators and and professional judgement; 3 = based on estimates from a similar building structure

[b] 50% of aggregate assumed to be left on site

Table 27: Scenarios – Waste Transport (modules A5, B2, B3, B4, C2)

Transportation Type	Rail, diesel (km)	Barge, residual fuel oil (km)	Road Short Haul, diesel (km)	Road Long Haul, diesel (km)
Secondary steel: site to waste processing[a]	99	534	0	753
All materials: to landfill	0	0	24	0

[a]default values from IE4B waste transport database

Table 28: Scenarios – Module D Assumptions

Material	Secondary Material (kg/kg product used)	Recovery Rate (kg/kg product used)	Net Output Flow[a] (kg/kg product used)
Steel Products			
Bolts, Fasteners, Clips	1.020	0.70	-0.320
Galvanized Decking	0.439	0.98	0.541
Galvanized Sheet	0.439	0.98	0.541
Galvanized Studs	0.439	0.98	0.541
Hollow Structural Steel	0.838	0.98	0.142
Nails	1.020	0.70	-0.320
Rebar, Rod, Light Sections	1.020	0.70	-0.320

Material	Secondary Material (kg/kg product used)	Recovery Rate (kg/kg product used)	Net Output Flow[a] (kg/kg product used)
Screws Nuts & Bolts	1.020	0.70	-0.320
Steel Plate	1.020	0.98	-0.040
Wide Flange Sections	1.020	0.98	-0.040
Wire Rod	1.020	0.70	-0.320
Aluminum Products	0.000	0.60	0.600
Extrusions	0.426	0.95	0.524
Window Frame	0.426	0.95	0.524
Cold Rolled Sheet	0.649	0.95	0.301
CLT and Glulam	0.000	0.80	0.800
Concrete Products	0.000	0.70	0.700

[a] negative value indicates that the system is a net consumer of secondary material

Table 29: Scenarios – Wood Product Biogenic Carbon Assumptions

Wood Product	Oven dry mass (kg/m^3)[a]	Wood species	Carbon content of wood (%)[b]
Cross Laminated Timber	378	Spruce	50.39%
Glulam Sections	470	D. Fir	50.50%
Parallel Strand Lumber	468	D. Fir	50.50%
Oriented Strand Board	544	?	50.00%
Small Dimension Softwood Lumber, kiln-dried	378	S-P-F	50.00%

[a] source: WoodWorks Carbon Calculator

[b] source: FPInnovation Carbon Tool B2C v2.18

Table 30: Scenarios – Concrete Carbonation Assumptions

Carbonation Parameter	Value
s factor	1
b factor	
50% fly ash	1.1
30% fly ash	1.075
<10% fly ash	1
k factor	
Wet/submerged	0.75
Buried	1
Exposed	1.5
Sheltered	4
Indoors	6
C (kg/m3)	
5000 PSI, 30% FA	369.3
5000 PSI, 50% FA	263.8
Mortar	307
Concrete masonry unit	137

Table 31: Scenarios – Particle Size Distribution of Crushed Concrete

Particle size (mm)	Proportion	Average radius (mm)
19-26.5	1%	11.375
13.2-19.0	11%	8.05
9.5-13.2	13%	5.675
4.75-9.5	22%	3.5625
2.36-4.75	12%	1.7775
0.425-2.36	22%	0.69625
0.075-0.425	12%	0.125
<0.075	6%	0.0375

Source: Collins

Appendix E: LCI Data Source Tables

Table 32: Data Sources Summary

LCI Data	Time Frame[a]	Geographical Represent-ativeness	Information Modules	Data Source
Common fossil fuels	2004-2008	North America	All	US LCI
Electricity generation and delivery	2004-2012	North America, British Columbia		
Transportation	2004-2010	North America		
Aluminum products	2014		A1, A3, B2 (paint only), B3, B4	Athena LCI
Steel products	2010			
Softwood lumber, oriented strand board, parallel strand board	2012	Canada, British Columbia		
Cross laminated timber	2013			
Glulam	2011			
Ready-mix concrete	2015			
Concrete Masonry Unit	2015			
Mortar	2005			
Gypsum board products	2012			
Glass mat panels	2015			
Joint compound and paper tape	1997			
Fibreglass and mineral wool batt insulation	2012			
Polyisocyanurate insulation	2011			
Extruded and expanded polystyrene insulation	2007			
Glazing	2013			
Polyethylene vapor retarder	2010			
Modified bitumen membrane	2013			
EPDM membrane	2009			
Roofing asphalt	2001			
Drainage Mat, root barrier	2013			
Metal roofing	2013			
Paint products	1999			
Coarse aggregate	2004			
Medium density fibreboard	2004-2013	North America (industry-average)		American Wood Council EPD
Resilient flooring	2012-2013			Resilient Floor Covering Institute EPD

LCI Data	Time Frame[a]	Geographical Represent-ativeness	Information Modules	Data Source
Ceramic tile flooring	2010-2014			Tile Council of North America EPD
Acoustic ceiling tile (assumed to be Mesa Ceiling Panels)	2014-2016	North America		Armstrong World Industries EPD
Carpet tiles (GLASBAC®, TYPE 6 NYLON and GLASBAC®RE, TYPE 66 NYLON)	2015-2016			Interface Americas EPDs
Trespa cladding (8mm Meteon Standard)	2009-2012	Netherlands (supplied to Vancouver)		Trespa International B.V. EPD
Biomass combustion	2012	North America	B6	Athena LCI
Water supply and waste water plants	2005, 2009	World (excluding Europe), adjusted to British Columbia	B7	Ecoinvent LCI
Steel scrap preprocessing	2013	North America	C3	Athena LCI
Landfilling and incineration	2012-2014	Quebec, adjusted to British Columbia	C4	Ecoinvent LCI
Steel scrap value	2011	North America	D	Athena LCI
Aluminum scrap value	2014		D	
Concrete crushing	2005		D	

[a]"Time Frame" is the period between the known initiation of data and its final update and/or validation

Table 33: LCI Data Substitutions

Material	Athena LCI Database Substitution(s)
Soil anchor tension reinforcement	Wire Rod
10 mil polyethylene	6 mil Polyethylene
Liquid applied vapour permeable membrane	Water Based Latex Paint
Semi rigid insulation	FG Batt R11-15
Air/vapour barrier	Modified Bitumen membrane
Asphalt overlay board	Oriented Strand Board, Roofing Asphalt
High temperature rated self adhered membrane	Modified Bitumen membrane
Polyurethane wood finish	Solvent Based Varnish

Material	Athena LCI Database Substitution(s)
1" shaft liner	5/8" Fire-Rated Type X Gypsum Board
Epoxy floor finish	Solvent Based Alkyd Paint
Curtain wall	Aluminum Extrusion
	EPDM membrane (black, 60 mil)
	Glazing Panel
	Screws Nuts & Bolts
Exterior glazed aluminum doors	Aluminum Extrusion
	Glazing Panel
	Nails
Exterior hollow metal doors	Galvanized Sheet
	Solvent Based Alkyd Paint
	Expanded Polystyrene
	Nails
Interior hollow metal doors	Galvanized Sheet
	Solvent Based Alkyd Paint
	Nails
Interior solid wood doors	Small Dimension Softwood Lumber, kiln-dried
	Water Based Latex Paint
	Nails