Athena Sustainable Materials Institute

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Ponderosa Commons Cedar House, University of British Columbia

An Environmental Building Declaration According to EN 15978 Standard

Photo courtesy of Zahra Teshnizi

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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) **Ponderosa Commons Cedar House** (herein referred to as Cedar House), the 18-storey tower portion of the Ponderosa Commons Phase II complex which serves as a student residence 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	March 2017
Assessment timing	Use phase (occupancy commenced March 2016)
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.

[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 Cedar House Life Cycle Environmental Impact Summary

EN 15978 Environmental Impact Indicator	Unit	Total
Global warming potential	kg CO_2 eq.	2.57E+07
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	8.35E-02
Acidification potential of land and water	kg SO_2 eq.	1.36E+05
Eutrophication potential	kg N eq.	3.57E+04
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.28E+06
Abiotic resource depletion potential of fossil fuels	MJ surplus	5.23E+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 Cedar House.
This document presents a model derived estimate of the environmental performance of Cedar House according to a standardized format in order to publicly communicate results in a transparent and comparable manner. The intended use of this assessment is for educating/informing building stakeholders about the environmental implications of the Cedar House design.

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 Cedar House, an 18-storey plus basement, 12,838 m^2 (138,187 ft^2) structure forming part of the mixed-use Ponderosa Commons Phase II complex (27,189 m^2, 292,658 ft^2) at 2075 West Mall, Vancouver, British Columbia – see Table 3 for the project directory, Figure 1 and Figure 2 for renderings of the Ponderosa Commons II complex showing the extent of Cedar House, and Figure 5 through Figure 6 for building photos.

Levels 3 through 18 of the tower include 14 four-bed suites, 1 two-bed Manager suite, 246 single-bed studios, and 6 single-bed VIP studios, for a total of 310 beds. Level 2 through the basement serve mixed-use purposes, including building services and storage facilities, student communal areas, and administrative offices.

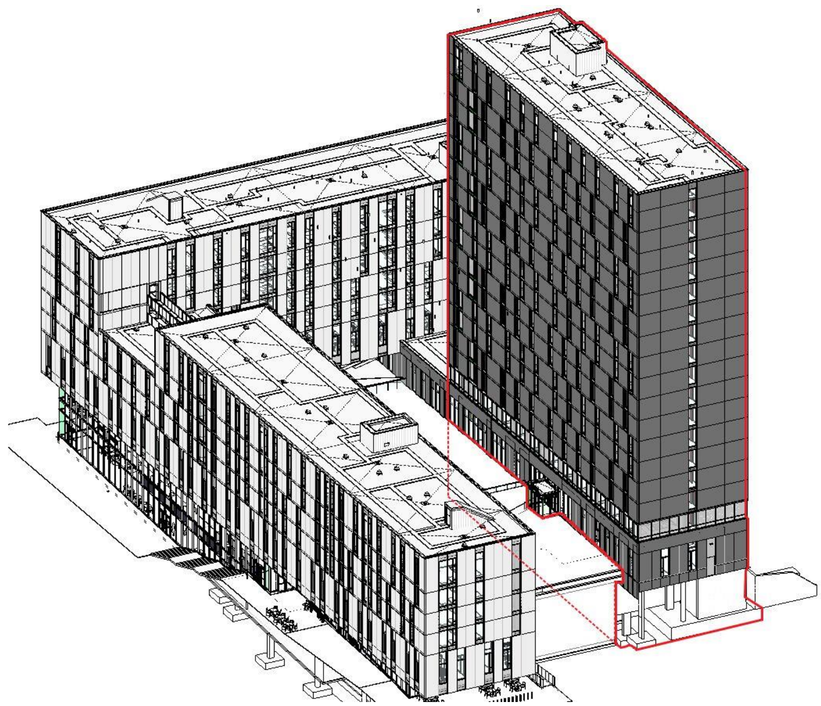
1.3 Assessment Verification

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

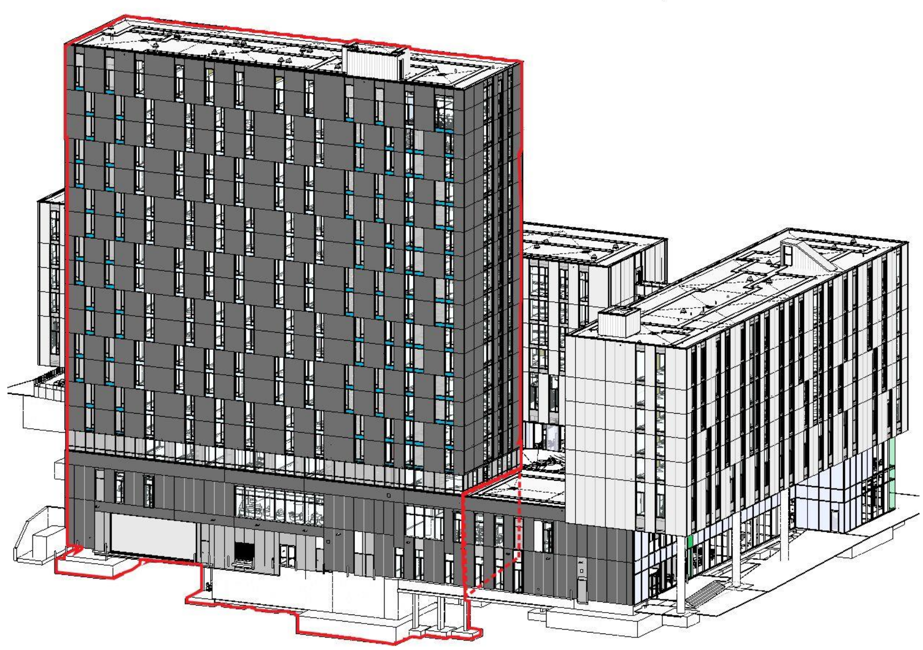
Table 3: Project Directory

Owner	University of British Columbia Properties Trust
Architect	Kuwabara Payne McKenna Blumberg Architects & Hughes Condon Marler Architects
Construction Manager	Urban One
Structural	Wicke Herfst Maver Consulting
Mechanical/Electrical/Lanscape/Sustainability	Stantec Consulting
Landscape	Hapa Collaborative
Civil	Kamps Engineering
Specifications	Keyword Specifications Inc
Code	GHL Consultants
Geotechnical	GeoPacific
Envelope	RDH Building Engineering Ltd.
Energy Modelling	EnerSys Analytics Inc.
Survey	Murray & Associates
Environmental	ACM Environmental
Elevator	Vertech Elevator Services Inc.
Commissioning	Seawood Solutions and Services Inc.



Rendering courtesy of KPMB Architects, HCMA & UBC

Figure 1: Rendering of Ponderosa II Complex Showing Extent of Cedar House



Rendering courtesy of KPMB Architects, HCMA & UBC

Figure 2: Rendering of Ponderosa II Complex Showing Extent of Cedar House

Photo courtesy of UBC

Figure 3: Exterior During Construction

Photo courtesy of UBC

Figure 4: Exterior During Construction

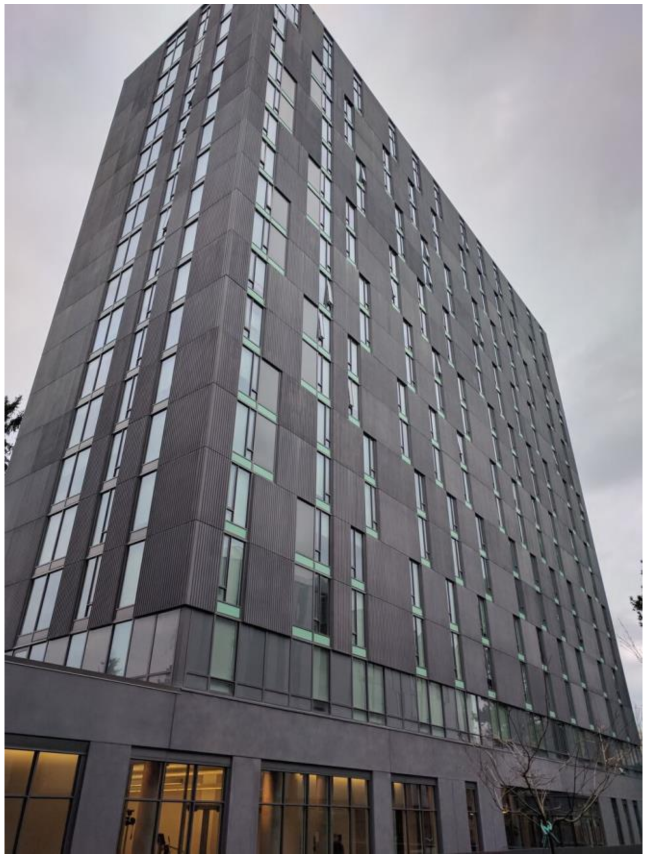


Photo courtesy of UBC

Figure 5: Cedar House Exterior

Photo courtesy of UBC

Figure 6: Cedar House Studio Interior

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 Cedar 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; LEED Gold certified (registered, pending)
Pattern of use	Study and social space, and residence for a maximum capacity of 310 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 the Ponderosa Commons Phase II Cedar House tower – see Figure 1 and Figure 2 for renderings illustrating the extent of what is included in assessment scope. The assessment 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, rubber flooring;
- Window sill finishes;
- Non-structural connections;
- Non-finish 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 two-way reinforced concrete suspended slabs supported by three rows of concrete columns (generally spaced at 4.00 m along rows and either 6.68m or 5.36m between rows), and slabs on grade at the 1st (partial) and basement levels. Overall lateral resistance is provided by two concrete stair/elevator cores which extend the height of the tower. The building's perimeter is supported by reinforced concrete basement walls on strip footings. The majority of columns are offset from the basement walls and are instead supported by spread footings; the stair/elevator cores are similarly supported by large spread footings.

Fenestration includes double pane low-e windows with 1.98 W/m2 °C U-value (0.35 Btu/hr-ft2-°F) and a small amount of curtain wall at the 2nd floor entrance area with 2.16 W/m2 °C U-value (0.38 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 mix of insulated and non-insulated precast panels, which have an average RSI value of 2.22 (R-value of 12.6). The roof envelope consists of a modified bitumen membrane assembly with 3.86 RSI value (R-value of 21.9).

Partitions are for the most part light gauge steel stud walls with 16 mm or 12 mm gypsum board and optionally fibreglass batt sound attenuation insulation. The basement includes some concrete block partition walls. 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" architectural drawings produced by Kuwabara Payne McKenna Blumberg Architects & Hughes Condon Marler Architects (dated February 28, 2014), and "Issued for Construction" structural drawings produced by Wicke Herfst Maver Consulting (dated February 28, 2014).

Suites are heated with electric baseboards and allows heating control of each bedroom rather than each unit. Cooling for the suites is provided by operable windows. When windows are opened the heating system is automatically shut off. Each suite's ductwork is located between the units.

The building's domestic hot water needs and space heating of the common areas (basement, level 1, and 2) is provided by UBC's Academic District Energy System (ADES), while cooling is provided by a heat pump. ADES is a network of hot water piping across the UBC Vancouver campus. The heating, ventilation and air conditioning (HVAC) system includes air handling units (AHUs) with heating and cooling coils that serve variable air volume terminal units (VAV boxes), as well as heat recovery ventilators (HRVs) with heating and cooling that serve fan coil units (FCUs) which also have heating and cooling coils.

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 7, 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.

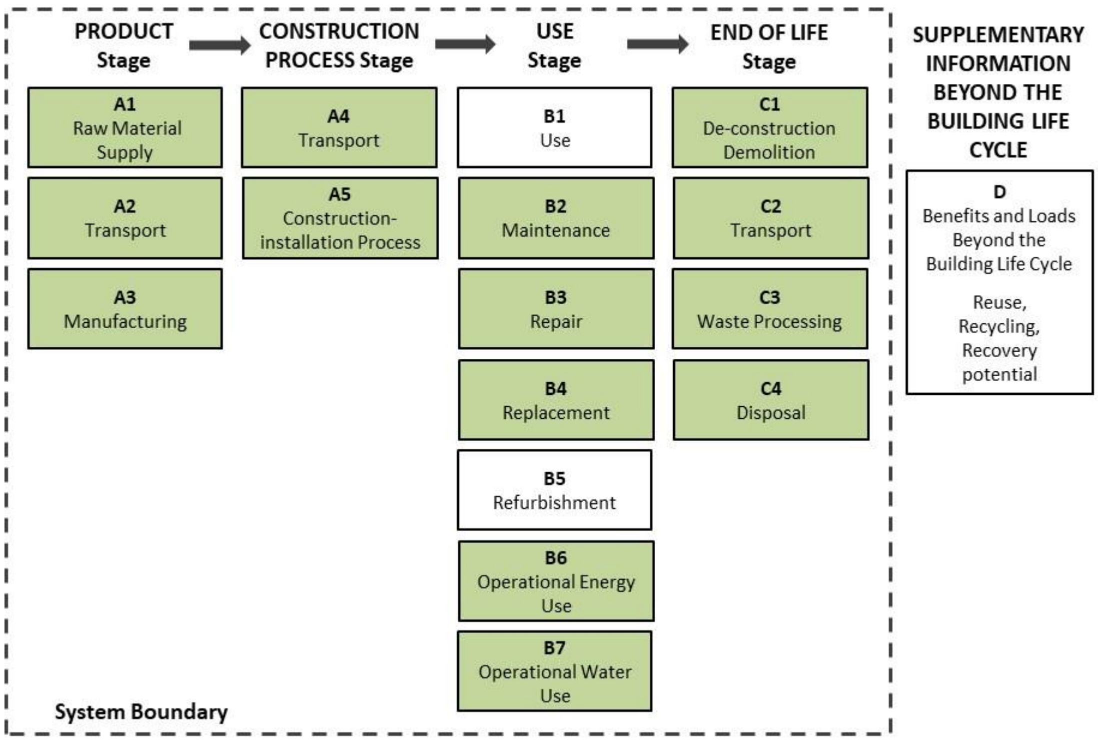


Figure 7: Assessment System Boundary

[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 7, 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; and
- Precast concrete wall panel products.

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):

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

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.

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

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.

[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 are 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):

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

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.

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 26 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)

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

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

[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.

[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.

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) – see Table 30 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.

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]

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

Environmental data from EPDs were used for the following products:

- Carpet tile
- Resilient flooring
- Ceramic tile flooring
- Acoustic ceiling tile

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.

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.

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.

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.

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[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

- *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).

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)

8.0 Communication of Assessment Results

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

- Table entries marked "xx" refer to information modules or environmental indictors that are not included in the study scope.

[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.

- 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 Cedar 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 8 through Figure 14 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]

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 analysis cases 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:

- **Case 1:** operational energy use estimates are increased by 10%;
- **Case 2:** ready-mix concrete quantities are increased by 10%; and
- **Case 3:** rebar quantities are increased by 10%.

[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.

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

Table 8: Cedar 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.	2.57E+07	2.00E+03	8.30E+04	2.57E+05	2.00E+01	8.30E+02
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	8.35E-02	6.50E-06	2.69E-04	8.35E-04	6.50E-08	2.69E-06
Acidification potential of land and water	kg SO_2 eq.	1.36E+05	1.06E+01	4.38E+02	1.36E+03	1.06E-01	4.38E+00
Eutrophication potential	kg N eq.	3.57E+04	2.78E+00	1.15E+02	3.57E+02	2.78E-02	1.15E+00
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.28E+06	1.00E+02	4.14E+03	1.28E+04	1.00E+00	4.14E+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	5.23E+07	4.07E+03	1.69E+05	5.23E+05	4.07E+01	1.69E+03
Resource Use							
Renewable primary energy excluding energy resources used as raw material	MJ	7.30E+08	5.68E+04	2.35E+06	7.30E+06	5.68E+02	2.35E+04
Renewable primary energy resources used as raw material	MJ	1.90E+06	1.48E+02	6.12E+03	1.90E+04	1.48E+00	6.12E+01
Non-renewable primary energy excluding resources used as raw material	MJ	3.80E+08	2.96E+04	1.22E+06	3.80E+06	2.96E+02	1.22E+04
Non-renewable primary energy resources used as raw material	MJ	6.76E+06	5.27E+02	2.18E+04	6.76E+04	5.27E+00	2.18E+02
Secondary material	kg	1.70E+06	1.32E+02	5.48E+03	1.70E+04	1.32E+00	5.48E+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	1.11E+06	8.62E+01	3.57E+03	1.11E+04	8.62E-01	3.57E+01
Waste Categories							
Non-hazardous waste disposed	kg	7.80E+06	6.08E+02	2.52E+04	7.80E+04	6.08E+00	2.52E+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	1.83E+05	1.43E+01	5.91E+02	1.83E+03	1.43E-01	5.91E+00
Materials for recycling	kg	1.15E+07	8.96E+02	3.71E+04	1.15E+05	8.96E+00	3.71E+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	3.44E+06	3.11E-02	1.58E+04	1.36E+03	2.32E+05	xx	3.07E+06
A4 Transport	1.24E+05	4.54E-06	1.21E+03	8.14E+01	4.16E+04	xx	2.19E+05
A5 Construction Installation Process	1.85E+05	1.46E-03	6.92E+02	6.74E+01	1.21E+04	xx	2.28E+05
B1 Use of Products	xx	xx	xx	xx	xx	xx	xx
B2 Maintenance	3.61E+04	1.47E-04	1.76E+02	6.52E+00	3.03E+03	xx	2.10E+05
B3 Repair	5.00E+05	1.06E-02	3.33E+03	1.63E+02	3.64E+04	xx	8.21E+05
B4 Replacement	8.72E+05	1.35E-02	5.20E+03	2.90E+02	5.90E+04	xx	1.46E+06
B5 Refurbishment	xx	xx	xx	xx	xx	xx	xx
B6a Operational Energy Use, building integrated	1.78E+07	3.60E-04	9.53E+04	2.12E+03	7.39E+05	xx	4.11E+07
B6b Operational Energy Use, plug loads	2.00E+06	6.67E-05	5.92E+03	2.44E+02	8.62E+04	xx	3.96E+06
B7 Operational Water Use	5.78E+05	2.17E-02	7.10E+03	3.13E+04	4.35E+04	xx	8.07E+05
C1 De-construction and Demolition	1.20E+05	4.97E-06	1.45E+02	1.18E+01	3.48E+03	xx	2.37E+05
C2 Transport	5.18E+04	2.03E-06	5.42E+02	3.47E+01	1.79E+04	xx	9.66E+04
C3 Waste Processing	1.55E+04	3.59E-07	1.63E+02	6.16E+00	3.11E+03	xx	2.94E+04
C4 Disposal	2.65E+04	4.55E-03	2.17E+02	1.97E+01	5.65E+03	xx	4.43E+04
Total	**2.57E+07**	**8.35E-02**	**1.36E+05**	**3.57E+04**	**1.28E+06**	**xx**	**5.23E+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	2.57E+06	8.97E+05	3.46E+07	2.09E+06	1.46E+06	xx	xx	2.94E+04
A4 Transport	8.15E+02	0.00E+00	1.54E+06	0.00E+00	0.00E+00	xx	xx	0.00E+00
A5 Construction Installation Process	2.50E+05	7.13E+04	1.93E+06	6.37E+04	5.41E+04	xx	xx	1.05E+03
B1 Use of Products	xx	xx	xx	xx	xx	xx	xx	xx
B2 Maintenance	6.02E+04	0.00E+00	2.48E+05	1.23E+06	0.00E+00	xx	xx	1.59E+01
B3 Repair	6.26E+05	5.41E+03	5.80E+06	1.21E+06	5.02E+04	xx	xx	3.41E+03
B4 Replacement	1.11E+06	9.24E+05	1.15E+07	2.17E+06	1.38E+05	xx	xx	6.52E+03
B5 Refurbishment	xx	xx	xx	xx	xx	xx	xx	xx
B6a Operational Energy Use, building integrated	6.18E+08	0.00E+00	2.81E+08	0.00E+00	0.00E+00	xx	xx	1.03E-03
B6b Operational Energy Use, plug loads	1.07E+08	0.00E+00	2.99E+07	0.00E+00	0.00E+00	xx	xx	1.92E-04
B7 Operational Water Use	3.84E+05	0.00E+00	9.92E+06	0.00E+00	0.00E+00	xx	xx	1.07E+06
C1 De-construction and Demolition	7.24E+02	0.00E+00	1.66E+06	0.00E+00	0.00E+00	xx	xx	0.00E+00
C2 Transport	2.90E+02	0.00E+00	6.83E+05	0.00E+00	0.00E+00	xx	xx	0.00E+00
C3 Waste Processing	2.41E+04	0.00E+00	2.72E+05	0.00E+00	0.00E+00	xx	xx	0.00E+00
C4 Disposal	3.28E+03	0.00E+00	3.66E+05	0.00E+00	0.00E+00	xx	xx	4.69E+00
Total	**7.30E+08**	**1.90E+06**	**3.80E+08**	**6.76E+06**	**1.70E+06**	**xx**	**xx**	**1.11E+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	1.92E+06	xx	xx	0.00E+00	5.21E+02	0.00E+00	0.00E+00
A4 Transport	1.32E+03	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
A5 Construction Installation Process	2.78E+05	xx	xx	1.02E+03	4.54E+05	0.00E+00	0.00E+00
B1 Use of Products	xx	xx	xx	xx	xx	xx	xx
B2 Maintenance	4.77E+04	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B3 Repair	1.90E+05	xx	xx	3.18E+04	3.34E+05	0.00E+00	0.00E+00
B4 Replacement	5.30E+05	xx	xx	6.44E+04	4.41E+05	0.00E+00	0.00E+00
B5 Refurbishment	xx	xx	xx	xx	xx	xx	xx
B6a Operational Energy Use, building integrated	3.93E+05	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B6b Operational Energy Use, plug loads	2.17E+04	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B7 Operational Water Use	9.65E+03	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1 De-construction and Demolition	1.30E+03	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C2 Transport	4.68E+02	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C3 Waste Processing	9.93E+01	xx	xx	8.60E+04	1.03E+07	0.00E+00	0.00E+00
C4 Disposal	4.41E+06	xx	xx	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	**7.80E+06**	**xx**	**xx**	**1.83E+05**	**1.15E+07**	**0.00E+00**	**0.00E+00**

Table 12: Sensitivity Analysis Results

EN 15978 Environmental Indicator	Unit	Case 1: 10% increase in operating energy use	Case 2: 10% increase in ready-mix concrete	Case 3: 10% increase in rebar
Environmental Impacts				
Global warming potential	kg CO_2 eq.	1.077	1.009	1.002
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	1.001	1.033	1.000
Acidification potential of land and water	kg SO_2 eq.	1.075	1.007	1.002
Eutrophication potential	kg N eq.	1.007	1.003	1.000
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.064	1.014	1.003
Abiotic resource depletion potential for elements	kg Sb eq.	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	1.086	1.003	1.001
Resource Use				
Renewable primary energy excluding energy resources used as raw material	MJ	1.099	1.000	1.000
Renewable primary energy resources used as raw material	MJ	1.000	1.000	1.000
Non-renewable primary energy excluding resources used as raw material	MJ	1.082	1.005	1.003
Non-renewable primary energy resources used as raw material	MJ	1.000	1.000	1.000
Secondary material	kg	1.000	1.039	1.032
Renewable secondary fuels	MJ	xx	xx	xx
Non-renewable secondary fuels	MJ	xx	xx	xx
Net use of fresh water	m^3	1.000	1.002	1.001
Waste Categories				
Non-hazardous waste disposed	kg	1.005	1.070	1.002
Hazardous waste disposed	kg	xx	xx	xx
Radioactive waste disposed	kg	xx	xx	xx
Output Flows Leaving the System				
Components for re-use	kg	1.000	1.000	1.000
Materials for recycling	kg	1.000	1.076	1.003
Materials for energy recovery (not being waste incineration)	kg	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.	-1.08E+05	-4.31E+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.
Environmental Impacts					
Global warming potential	kg CO_2 eq.	1.29E+05	-1.92E+05	-3.12E+04	-3.41E+05
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	0.00E+00	-9.20E-06	-8.29E-07	0.00E+00
Acidification potential of land and water	kg SO_2 eq.	2.94E+02	-1.36E+03	-3.52E+02	0.00E+00
Eutrophication potential	kg N eq.	5.11E+00	-2.10E+01	-1.54E+01	0.00E+00
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	2.87E+03	-1.05E+04	-7.92E+03	0.00E+00
Abiotic resource depletion potential for elements	kg Sb eq.	xx	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	1.05E+03	-1.26E+05	-5.90E+04	0.00E+00
Resource Use					
Renewable primary energy excluding energy resources used as raw material	MJ	0.00E+00	-1.21E+06	-3.84E+04	0.00E+00
Renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non-renewable primary energy excluding resources used as raw material	MJ	7.29E+05	-1.95E+06	-5.24E+05	0.00E+00
Non-renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Secondary material	kg	8.47E+04	-2.80E+04	-1.02E+07	0.00E+00
Renewable secondary fuels	MJ	xx	xx	xx	xx
Non-renewable secondary fuels	MJ	xx	xx	xx	xx
Net use of fresh water	m^3	0.00E+00	-1.39E+03	0.00E+00	0.00E+00
Waste Categories					
Non-hazardous waste disposed	kg	-3.20E+03	-7.96E+04	-1.58E+02	0.00E+00
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	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
Materials for energy recovery (not being waste incineration)	kg	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

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.

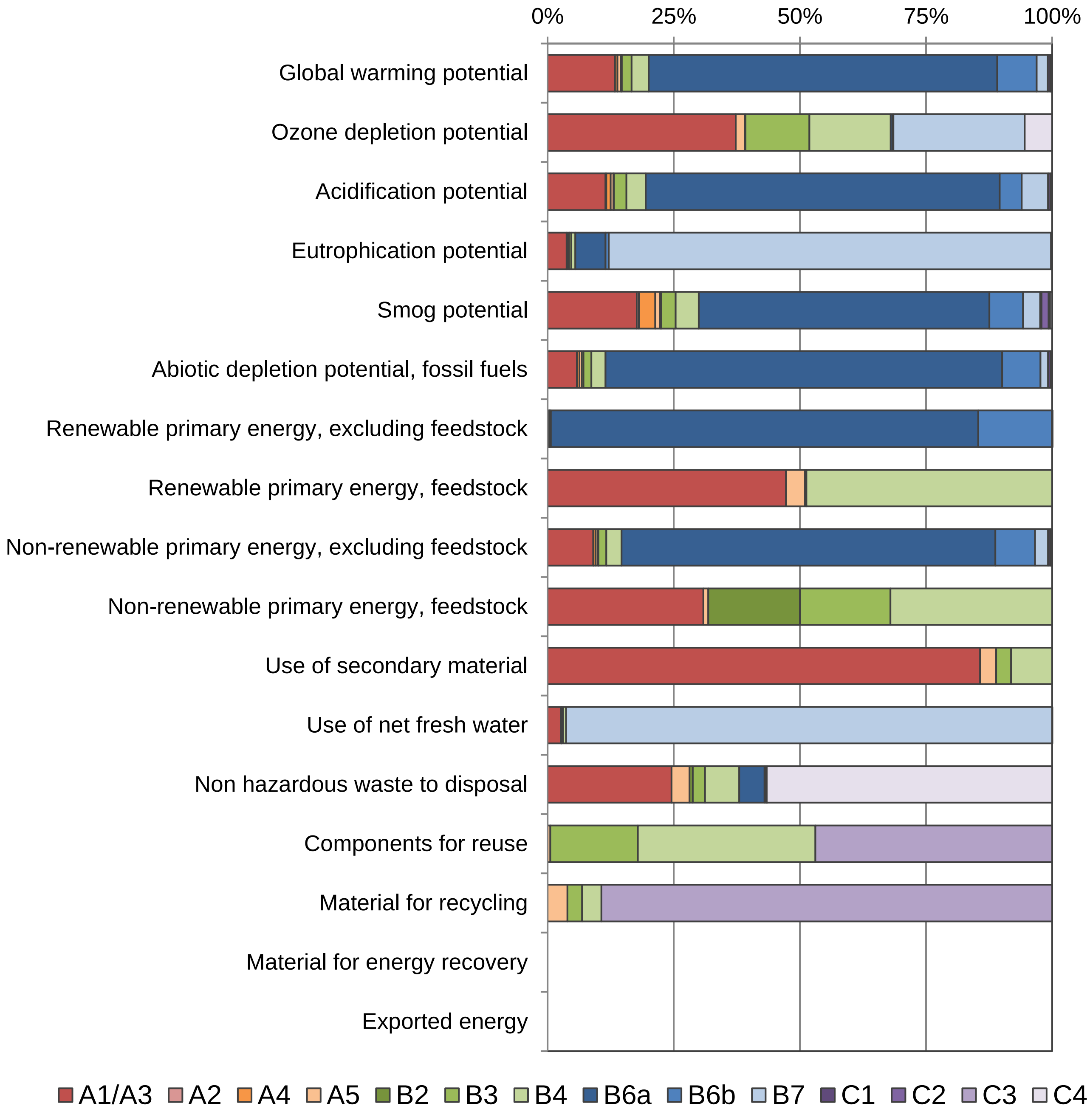

Figure 8: Information Module Contributions to Total LCA Results

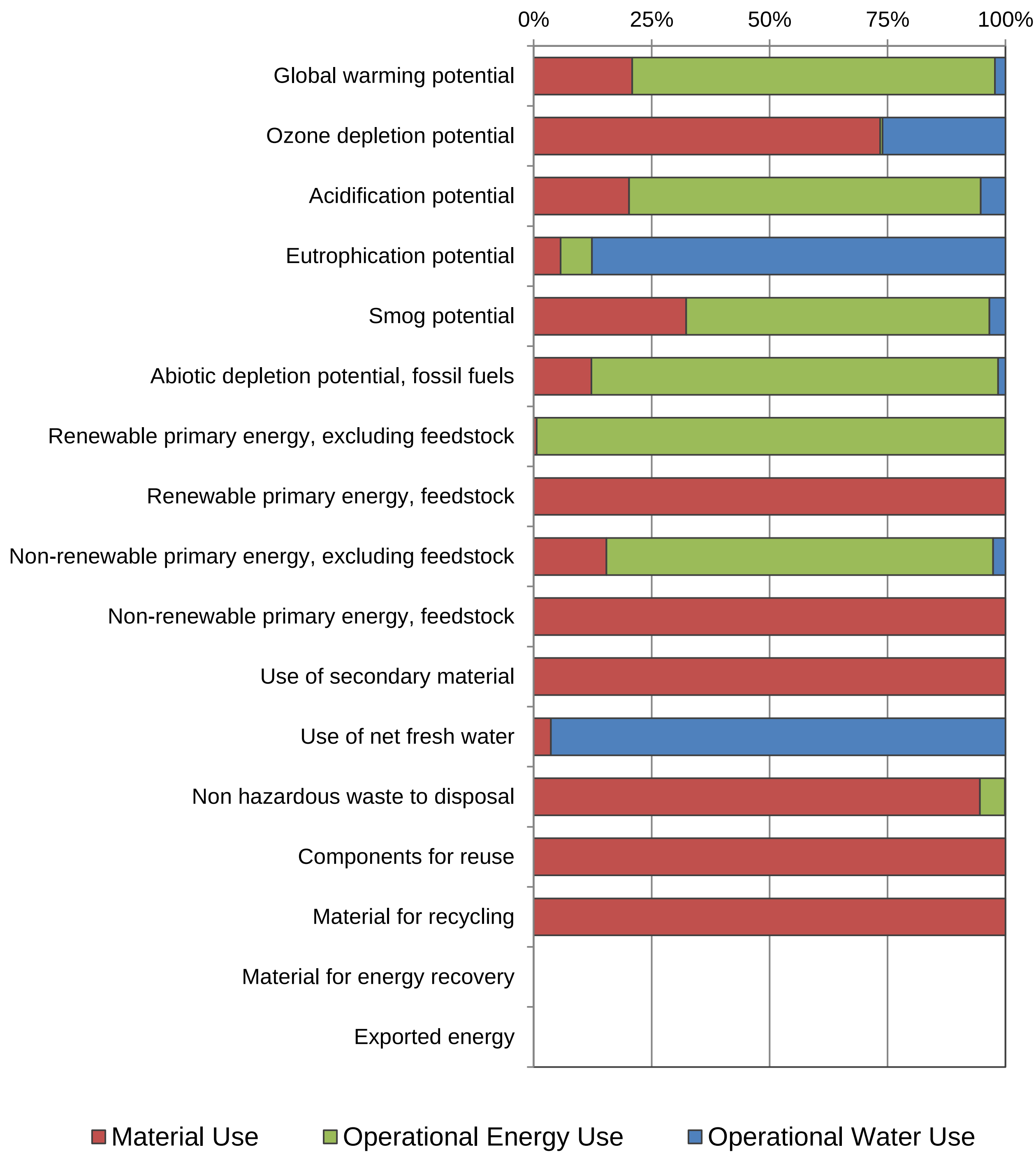

Figure 9: Resource Type Contributions to Total LCA Results

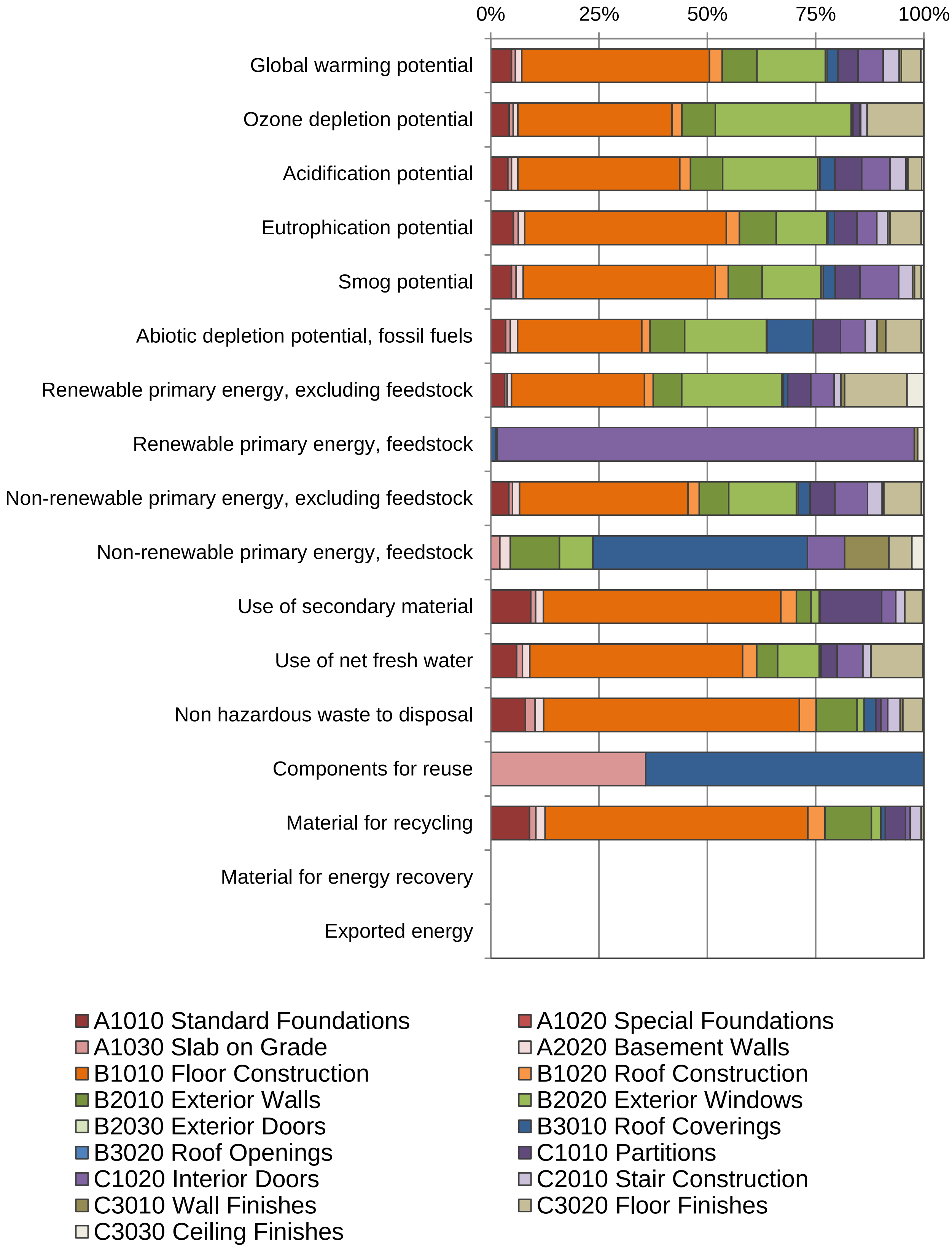
0%
25%
50%
75%
100%
Global warming potential
Ozone depletion potential
Acidification potential
Eutrophication potential
Smog potential
Abiotic depletion potential, fossil fuels
Renewable primary energy, excluding feedstock
Renewable primary energy, feedstock
Non-renewable primary energy, excluding feedstock
Non-renewable primary energy, feedstock
Use of secondary material
Use of net fresh water
Non hazardous waste to disposal
Components for reuse
Material for recycling
Material for energy recovery
Exported energy
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
C3020 Floor Finishes
C3030 Ceiling Finishes

Figure 10: Construction Element Contributions to Material Use LCA Results

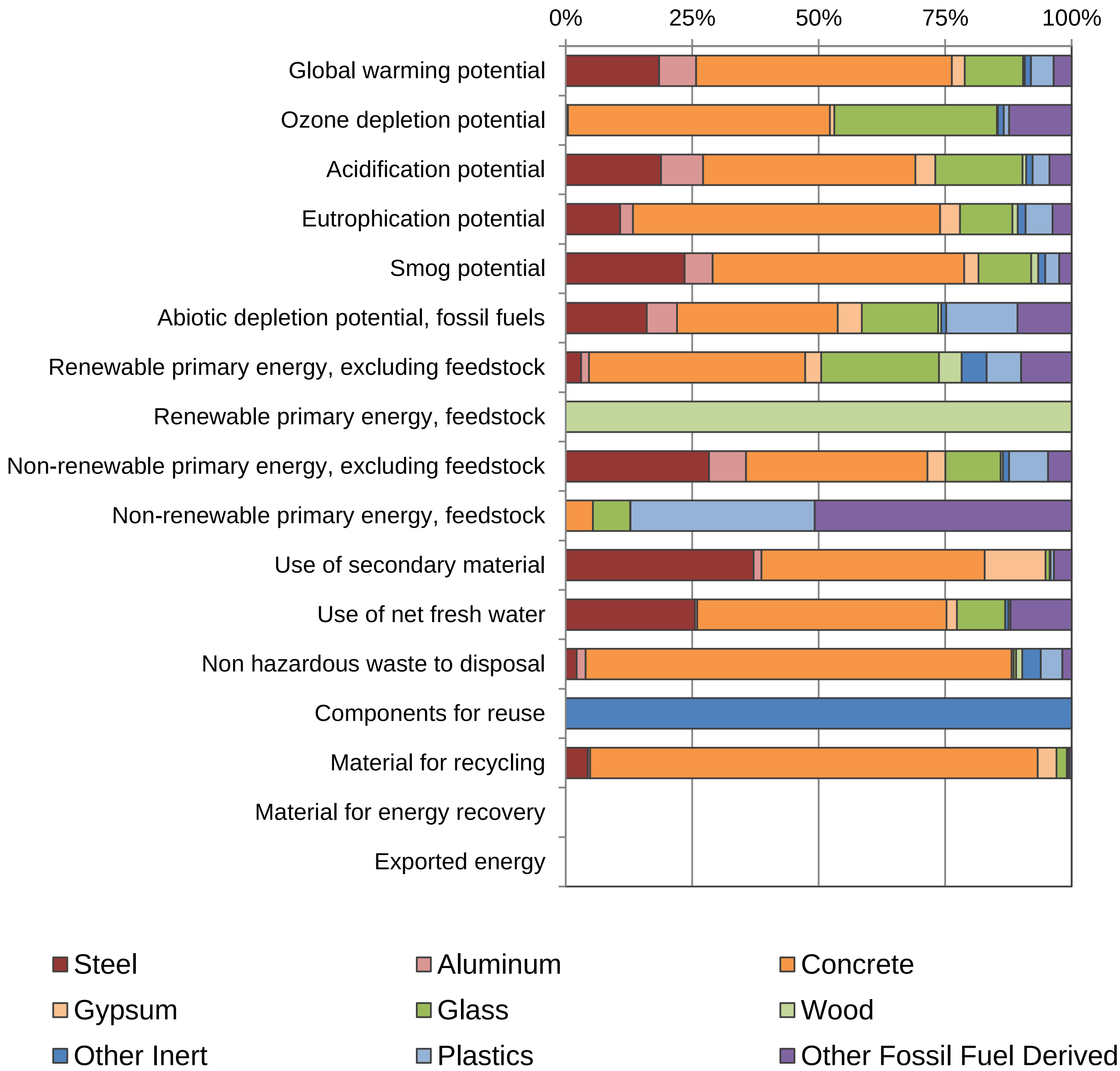

Figure 11: Material Type[23] Contributions to Material Use LCA Results

[23] The various "material types" noted in Figure 11 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.

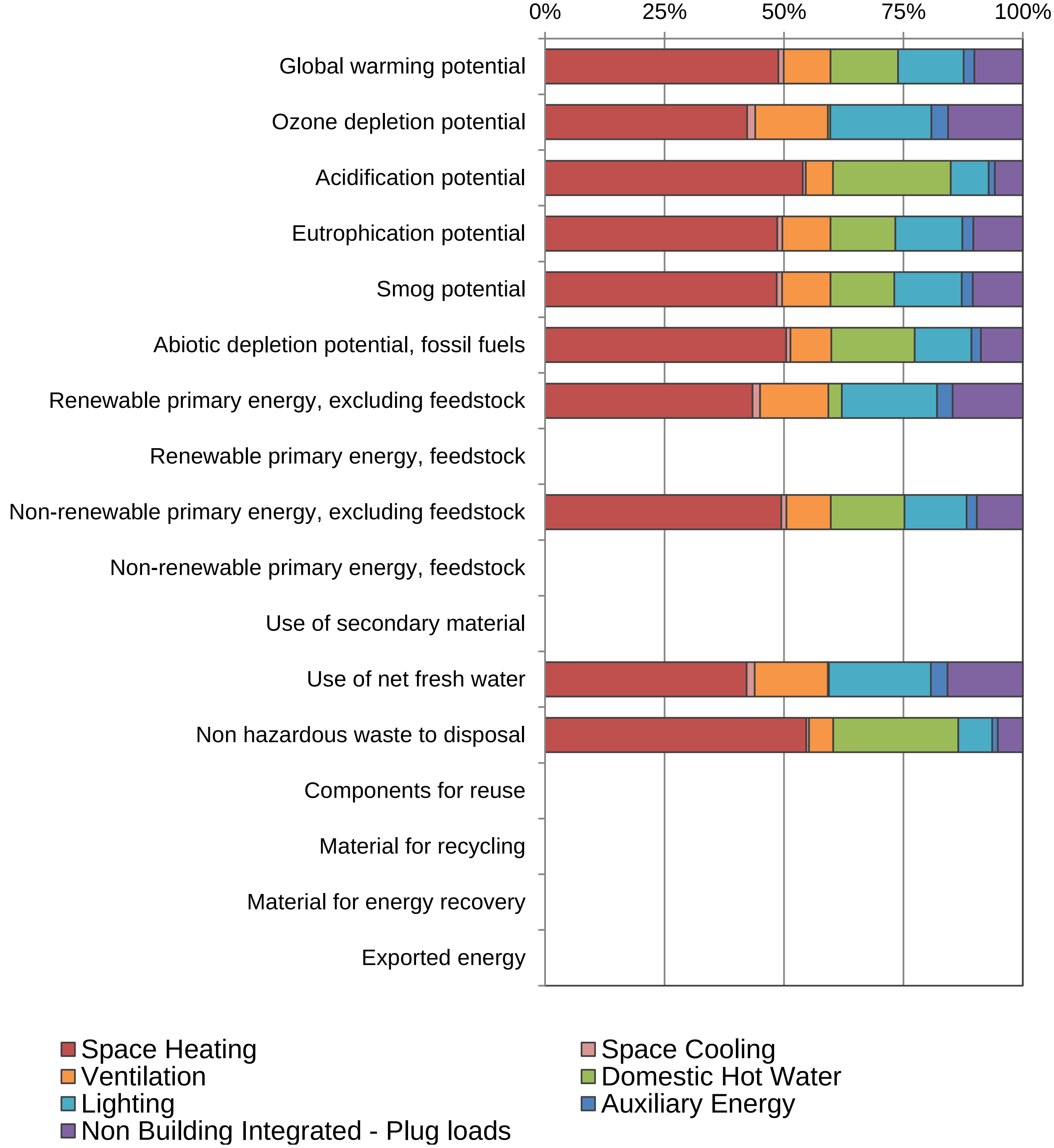

Figure 12: End-use Contributions to Operational Energy LCA Results

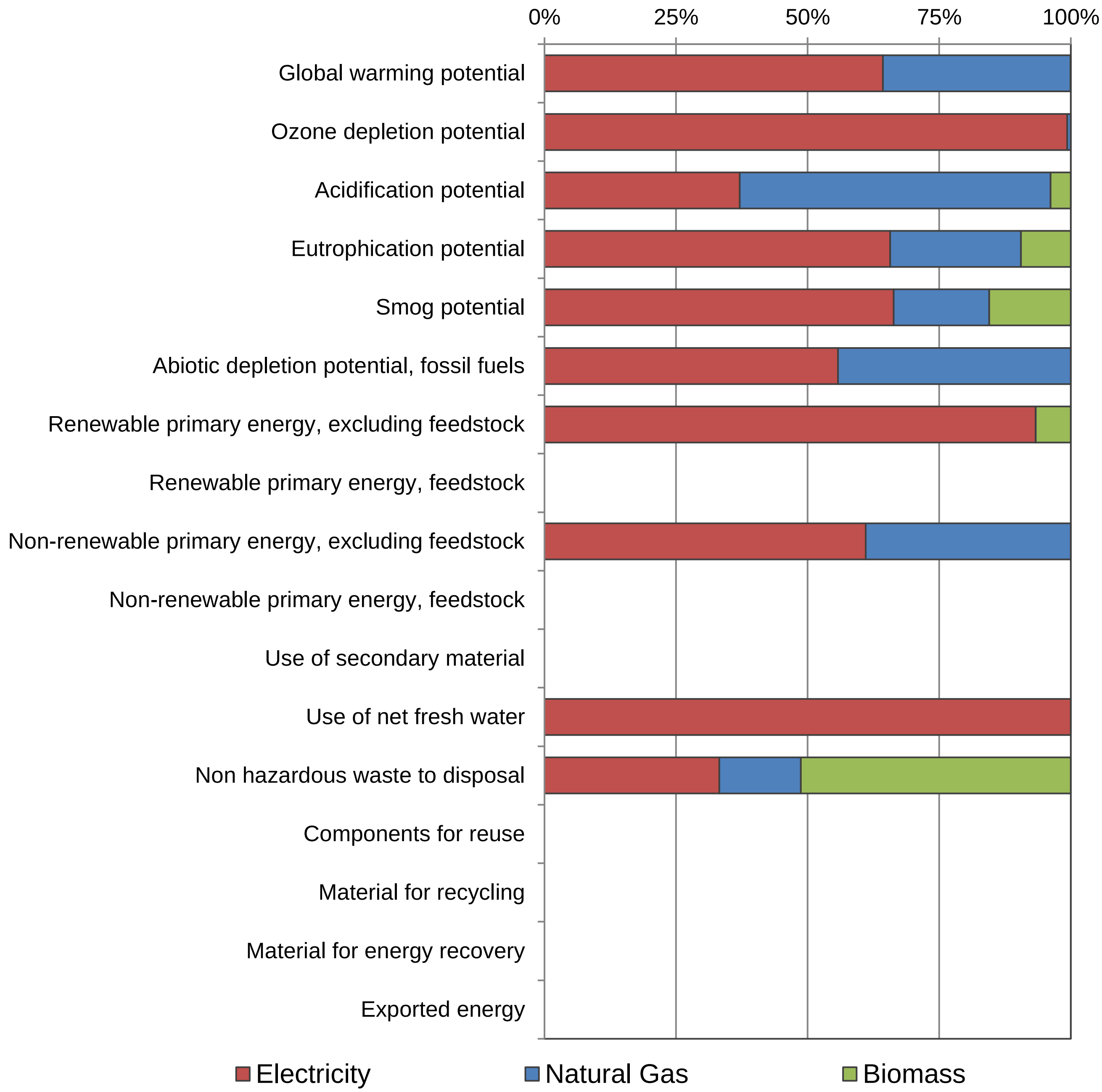

Figure 13: Fuel Type Contributions to Operational Energy LCA Results

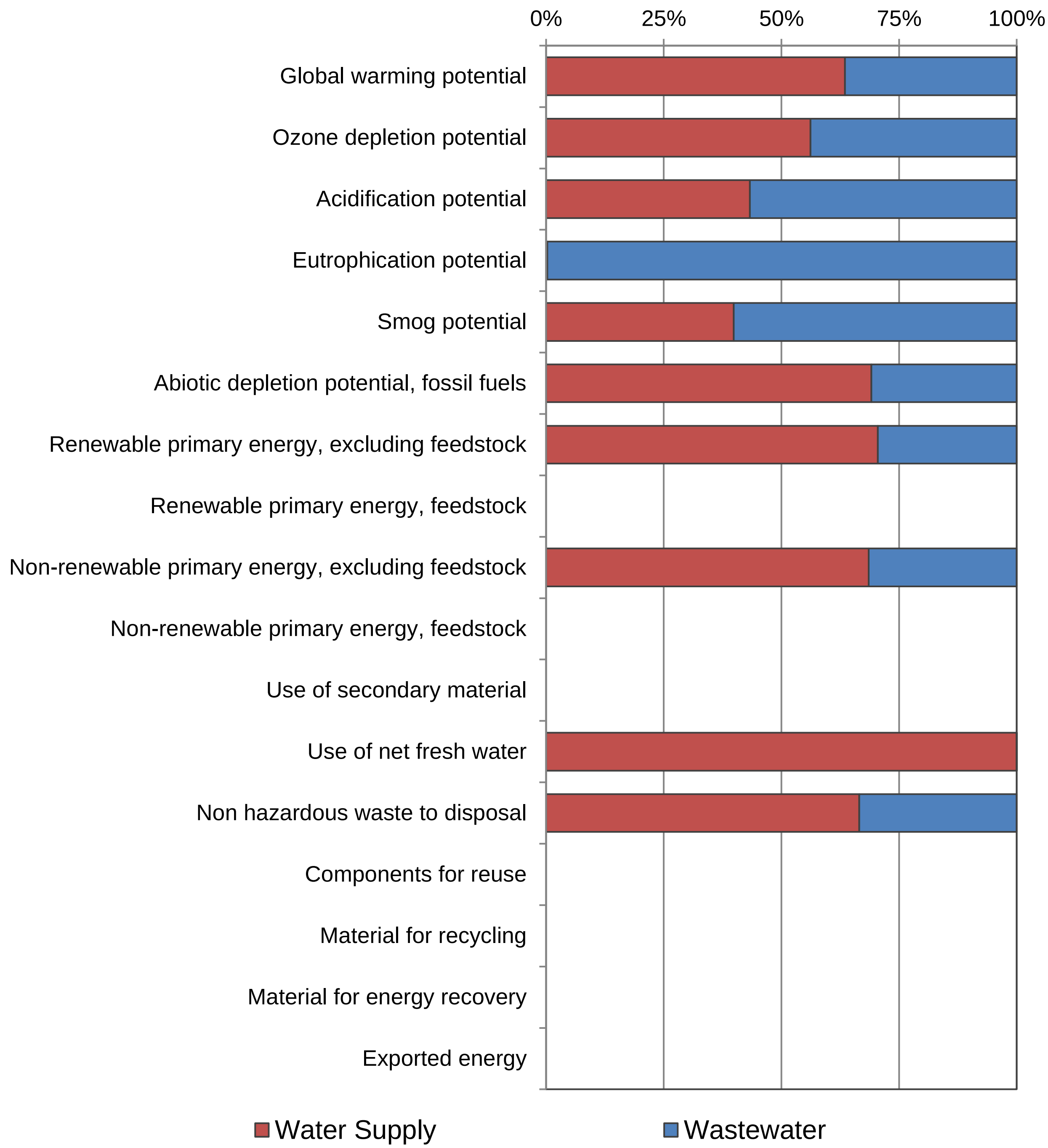

Figure 14: Water Flow Type Contributions to Operational Water LCA Results

Appendix B: Building Element Design Summary

Table 15: Building Element Design Summary

Element	Design Summary
A1010 Standard Foundations	• 2500x2500x850, 3000x3000x1000, 3500x3500x1100, 5200x4300x800, 12000x7000x1600, 11000x12000x2000 reinforced concrete pad footings • 450x300, 600x200 reinforced concrete strip footings • 1600 deep raft footings
A1020 Special Foundations	*No special foundations*
A1030 Slab on Grade	• 100, 150 reinforced concrete slab with 50 XPS, 6 mil polyethylene
A2010 Basement Excavation	*Not included in scope*
A2020 Basement Walls	• 300, 400 reinforced concrete walls with 50 extruded polystyrene insulation, waterproof membrane, drainage mat, protection board
B1010 Floor Construction	• Walls: 200, 300, 350, 375, 400 reinforced concrete • Floors: 190, 250, 300, 375 reinforced concrete slabs • Columns: 600ϕ, 800ϕ, 800x400, 850x300, 850x300, 900x250, 900x300, 900x350, 900x600, 1200x250, 1200x300, 1200x350, 1200x400, 1500x400 reinforced concrete • Beams: misc. reinforced concrete • Misc. structural steel
B1020 Roof Construction	• Walls: 200, 400 reinforced concrete • Floors: 150, 190 reinforced concrete slabs • Columns: 900x250, 900x300, 1200x250 reinforced concrete
B2010 Exterior Walls	• 225 insulated precast panel, 90 precast panel • Misc. envelope assemblies, including metal panel and brick cladding
B2020 Exterior Windows	• Aluminum framed curtain wall • Aluminum framed double glazed windows
B2030 Exterior Doors	• Steel overhead rolling, insulated hollow metal, glazed doors
B3010 Roof Coverings	• 50 ballast, 100 extruded polystyrene insulation, modified bitumen membrane
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, hollow metal with glazing, solid wood, aluminum glazed doors
C1030 Fittings	*Not included in scope*
C2010 Stair Construction	• Reinforced concrete stairs, aluminum rails/balustrades
C2020 Stair Finishes	*No stair finishes*
C3010 Wall Finishes	• Paint (on gypsum board), cedar rough sawn, ceramic tile
C3020 Floor Finishes	• Carpet tile, resilient flooring, ceramic tile, epoxy paint (on concrete)
C3030 Ceiling Finishes	• Paint (on gypsum board), acoustic tile systems, suspended wood ceiling

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/Assembly	Total	Unit
1/2" Fire-Rated Type X Gypsum Board	13.100	m2
1/2" Moisture Resistant Gypsum Board	7.200	m2
1/2" Regular Gypsum Board	3382.894	m2
1/2" Glass Mat Gypsum Panel	423.600	m2
4" Normal Weight Concrete Block	1332.500	Blocks
5/8" Fire-Rated Type X Gypsum Board	22645.650	m2
5/8" Regular Gypsum Board	3570.800	m2
6 mil Polyethylene	861.090	m2
8" Lightweight Concrete Block	3560.000	Blocks
8" Normal Weight Concrete Block	4035.000	Blocks
Aluminum Cold Rolled Sheet	0.205	Tonnes
Aluminum Extrusion	6.204	Tonnes
Aluminum Window Frame	8415.265	kg
Ballast (aggregate stone)	38934.000	kg
Carpet Tile, Interface 1000 Series	392.840	m2
Carpet Tile, Interface Flor/Super Flor	125.700	m2
Carpet Tile, Interface Urban Retreat	1327.940	m2
Ceiling Tile	1004.900	m2
Ceramic tile flooring	171.040	m2
Coarse Aggregate Crushed Stone	131.255	tonnes
Cold Rolled Sheet	0.021	tonnes
Concrete Benchmark 4000 psi 25% FA	184.840	m3
Concrete Benchmark 4000 psi 35% FA	67.879	m3
Concrete Benchmark 4000 psi 40% FA	190.344	m3
Concrete Benchmark 5000 psi 20% FA	3129.131	m3
Concrete Benchmark 5000 psi 25% FA	1066.280	m3
Concrete Benchmark 5000 psi 40% FA	398.400	m3
Concrete Brick	94.500	m2
Double Glazed Soft Coated Argon	1534.400	m2
EPDM membrane (black, 60 mil)	8.080	kg
Expanded Polystyrene	96.429	m2 (25mm)
Extruded Polystyrene	8473.517	m2 (25mm)
FG Batt R11-15	17718.061	m2 (25mm)

Material/Assembly	Total	Unit
FG Batt R20	2667.200	m2 (25mm)
Galvanized Sheet	42.844	tonnes
Galvanized Studs	27.591	tonnes
Glazing Panel	8.749	tonnes
Hollow Structural Steel	1.605	tonnes
Joint Compound	18.789	tonnes
MBS Metal Wall Cladding - Commercial (24 Ga.)	147.600	m2
Modified Bitumen membrane	7644.744	kg
Mortar	17.231	m3
MW Batt R11-15	14436.013	m2 (25mm)
Nails	3.470	tonnes
Paper Tape	0.227	tonnes
Pine Wood tongue and groove siding	102.400	m2
Polyiso Foam Board (unfaced)	303.485	m2 (25mm)
Precast Insulated Panel	3290.900	m2
Precast Panel	1583.243	m2
Rebar, Rod, Light Sections	491.375	tonnes
Resilient flooring	6293.600	m2
Screws Nuts & Bolts	0.021	tonnes
Small Dimension Softwood Lumber, kiln-dried	98.622	m3
Softwood Plywood	244.978	m2 (9mm)
Solvent Based Alkyd Paint	7315.493	L
Spandrel Panel	5.550	tonnes
Steel Plate	1.995	tonnes
Triple Glazed Soft Coated Argon	175.300	m2
VR 1/2" Drainage Mat	1184.624	m2
VR Separation Fabric	743.400	m2
Water Based Latex Paint	11719.823	L
Wide Flange Sections	0.942	tonnes
Wire Rod	1.097	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" Fire-Rated Type X Gypsum Board	130				
1/2" Moisture Resistant Gypsum Board	130				
1/2" Regular Gypsum Board	130				
1/2" Glass Mat Gypsum Panel	130				
4" Normal Weight Concrete Block	60				
5/8" Fire-Rated Type X Gypsum Board	130				
5/8" Regular Gypsum Board	130				
6 mil Polyethylene	55		4,137		
8" Lightweight Concrete Block	60				
8" Normal Weight Concrete Block	60				
Aluminum Cold Rolled Sheet		1,710			
Aluminum Extrusion		1,710			
Aluminum Window Frame		2,624			
Ballast (aggregate stone)	60				
Carpet Tile, Interface 1000 Series		805			
Carpet Tile, Interface Flor/Super Flor		805			
Carpet Tile, Interface Urban Retreat		805			
Ceiling Tile		478			
Ceramic tile flooring		805			
Coarse Aggregate Crushed Stone	60				
Cold Rolled Sheet	25		4,137		
Concrete Benchmark 4000 psi 25% FA	10.6				
Concrete Benchmark 4000 psi 35% FA	10.6				
Concrete Benchmark 4000 psi 40% FA	10.6				
Concrete Benchmark 5000 psi 20% FA	10.6				
Concrete Benchmark 5000 psi 25% FA	10.6				
Concrete Benchmark 5000 psi 40% FA	10.6				
Concrete Brick	155				
Double Glazed Soft Coated Argon		500			

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)
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 Sheet	25		4,137		
Galvanized Studs	25		4,137		
Glazing Panel		500			
Hollow Structural Steel	25		4,137		
Joint Compound		531			
MBS Metal Wall Cladding - Commercial (24 Ga.)	85		4,537		
Modified Bitumen membrane	170	390			
Mortar	60				
MW Batt R11-15	104	511			
Nails	60				
Paper Tape	130	412			
Pine Wood tongue and groove siding		377			
Polyiso Foam Board (unfaced)		3,298			
Precast Insulated Panel	24.6				
Precast Panel	24.6				
Rebar, Rod, Light Sections	60				
Resilient flooring		805			
Screws Nuts & Bolts	60				
Small Dimension Softwood Lumber, kiln-dried		337			
Softwood Plywood	55				
Solvent Based Alkyd Paint	90				
Spandrel Panel	25		4,137		
Steel Plate	33		3,164		
Triple Glazed Soft Coated Argon		500			
VR 1/2" Drainage Mat		300			
VR Separation Fabric		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	16,850	498	37,992
B2	144	0	0
B3	958	0	0
B4	1,801	0	0

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

Material/Assembly	Construction Waste Factor
1/2" Fire-Rated Type X Gypsum Board	1.100
1/2" Moisture Resistant Gypsum Board	1.100
1/2" Regular Gypsum Board	1.100
1/2" Glass Mat Gypsum Panel	1.100
4" Normal Weight Concrete Block	1.050
5/8" Fire-Rated Type X Gypsum Board	1.100
5/8" Regular Gypsum Board	1.100
6 mil Polyethylene	1.020
8" Lightweight Concrete Block	1.050
8" Normal Weight Concrete Block	1.050
Aluminum Cold Rolled Sheet	1.010
Aluminum Extrusion	1.010
Aluminum Window Frame	1.000
Ballast (aggregate stone)	1.050
Carpet Tile, Interface 1000 Series	1.050
Carpet Tile, Interface Flor/Super Flor	1.050
Carpet Tile, Interface Urban Retreat	1.050
Ceiling Tile	1.050
Ceramic tile flooring	1.050
Coarse Aggregate Crushed Stone	1.000
Concrete Benchmark 4000 psi 25% FA	1.050
Concrete Benchmark 4000 psi 35% FA	1.050
Concrete Benchmark 4000 psi 40% FA	1.050
Concrete Benchmark 5000 psi 20% FA	1.050
Concrete Benchmark 5000 psi 25% FA	1.050
Concrete Benchmark 5000 psi 40% FA	1.050
Concrete Brick	1.050
Double Glazed Soft Coated Argon	1.000

Material/Assembly	Construction Waste Factor
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 Sheet	1.010
Galvanized Studs	1.010
Glazing Panel	1.000
Hollow Structural Steel	1.010
Joint Compound	1.070
MBS Metal Wall Cladding - Commercial (24 Ga.)	1.010
Modified Bitumen membrane	1.030
Mortar	1.150
MW Batt R11-15	1.050
Nails	1.030
Paper Tape	1.050
Pine Wood tongue and groove siding	1.100
Polyiso Foam Board (unfaced)	1.050
Precast Insulated Panel	1.000
Precast Panel	1.000
Rebar, Rod, Light Sections	1.010
Resilient flooring	1.050
Screws Nuts & Bolts	1.030
Small Dimension Softwood Lumber, kiln-dried	1.080
Solvent Based Alkyd Paint	1.020
Spandrel Panel	1.010
Steel Plate	1.010
Triple Glazed Soft Coated Argon	1.000
VR 1/2" Drainage Mat	1.020
VR Separation Fabric	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 solid wood doors	Water Based Latex Paint	4	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 4000 psi 40% FA	15	2	1
	Rebar, Rod, Light Sections	15	2	1
	6 mil Polyethylene	15	2	1
	Polyiso Foam Board (unfaced)	15	2	1
	Extruded Polystyrene	15	2	1
	6 mil Polyethylene	15	2	1
Gypsum Board	1/2" Fire-Rated Type X Gypsum Board	20	2	1
	1/2" Moisture Resistant Gypsum Board	20	2	1
	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
Precast Panels	Precast Insulated Panel	25	2	1
	Precast Panel	25	2	1
	Extruded Polystyrene	25	2	1
Metal cladding	MBS Metal Wall Cladding - Commercial	20	2	1
Concrete block veneer	4" Normal Weight Concrete Block	25	2.0	1
	Mortar	30	25.0	1
Windows	Double Glazed Soft Coated Argon	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	Ballast (aggregate stone)	1	1.5	3
	VR Separation Fabric	1	1.5	3
	Extruded Polystyrene	1	1.5	3
	Modified Bitumen membrane	1	1.5	3

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Source[a]
Aluminum and glass doors	Aluminum Extrusion	12	12	1
	Glazing Panel	12	12	1
	Nails	12	12	1
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 20% 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
Stair Finishes	Solvent Based Alkyd Paint	15	2	1
	Small Dimension Softwood Lumber, kiln-dried	10	2	1
	Ceramic tile	10	2	1
Floor finishes	Carpet Tile, Interface Urban Retreat	2	2	1
	Carpet Tile, Interface 1000 Series	2	2	1
	Carpet Tile, Interface Flor/Super Flor	2	2	1
	Resilient flooring	9	2	1
	Ceramic tile flooring	15	2	1
	Water Based Latex Paint	15	2	1
	Solvent Based Alkyd Paint	15	2	1
Ceiling finishes	Ceiling Tile	9	2	1
	Galvanized Studs	9	2	1
	Pine Wood tongue and groove siding	10	2	1
	Galvanized Studs	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 4000 psi 40% FA	75	100	1
	Rebar, Rod, Light Sections	75	100	1
	6 mil Polyethylene	75	100	1
	Polyiso Foam Board (unfaced)	75	100	1
	Extruded Polystyrene	75	100	1
	6 mil Polyethylene	75	100	1
Gypsum Board	1/2" Fire-Rated Type X Gypsum Board	75	100	1
	1/2" Moisture Resistant Gypsum Board	75	100	1
	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

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)[a]	Material Use % ($P_{x,y}$)	Source[b]
	Joint Compound	75	100	1
	Paper Tape	75	100	1
Precast Panels	Precast Insulated Panel	100	100	1
	Precast Panel	100	100	1
	Extruded Polystyrene	100	100	1
Metal cladding	MBS Metal Wall Cladding - Commercial	50	100	4
Windows	Double Glazed Soft Coated Argon	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	Ballast (aggregate stone)	21	80	3
	VR Separation Fabric	21	100	3
	Extruded Polystyrene	21	80	3
	Modified Bitumen membrane	21	80	3
Interior Glazing	Glazing Panel	50	100	1
	Hollow Structural Steel	50	100	1
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

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)[a]	Material Use % ($P_{x,y}$)	Source[b]
	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
	Galvanized Studs	70	100	4
	Pine Wood tongue and groove siding	75	100	1
	Galvanized Studs	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 (B6)

Energy[a] Type	Quantity	Unit
Natural Gas	28,937	m^3
Electricity	1,903,203	kWh
Biomass	23,060	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	10,666
To Municipal Wastewater	10,666

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

Module	Diesel (L)
B2	0
B3	773
B4	1,183
C1	39,698

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		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	99	534	0	753
All materials: sorting plant to landfill/incineration	0	0	24	0

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			
Cold Rolled Sheet	0.177	0.98	0.803
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
MBS Metal Wall Cladding - Commercial (24 Ga.)	0.245	0.98	0.735
Nails	1.020	0.70	-0.320
Rebar, Rod, Light Sections	1.020	0.70	-0.320
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
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]
Oriented Strand Board/plywood	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	
<10% fly ash	1
10-20% fly ash	1.05
20-30% fly ash	1.08
40-60% fly ash	1.1
k factor	
Wet/submerged	0.75
Buried	1
Exposed	1.5
Sheltered	4
Indoors	6
C (kg/m3)	
4000 psi 25% FA	314
4000 psi 35% FA	271
4000 psi 40% FA	251
5000 psi 20% FA	422
5000 psi 25% FA	396
5000 psi 40% FA	317
Mortar	307
Concrete masonry unit	137
Precast	354

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	2012	Canada, British Columbia		
Pine Wood tongue and groove siding	2009			
Ready-mix concrete	2015			
Concrete masonry units	2015			
Concrete brick	2005			
Mortar	2005			
Precast concrete products	2011			
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			
Drainage Mat, separation fabric	2013			
Metal wall cladding	2013			
Paint products	1999			
Coarse aggregate	2004			
Resilient flooring	2012-2013	North America (industry-average)		Resilient Floor Covering Institute EPD
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

LCI Data	Time Frame[a]	Geographical Represent-ativeness	Information Modules	Data Source
				Industries EPD
Carpet tiles (Type 6,6 Nylon with GlasBacRE, GLASBAC®RE, TYPE 6 NYLON, Graphlar® Backing & Needlefelt)	2015-2016			Interface Americas EPDs
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/EPD Substitution(s)
Semi rigid insulation	MW Batt R11-15
Basement wall water proofing membrane, self-adhered roof membrane	Modified Bitumen membrane
Basement wall protection Board	VR 1/2" Drainage Mat
1" shaft liner	5/8" Fire-Rated Type X Gypsum Board
Epoxy floor finish	Solvent Based Alkyd Paint
Vinyl wood flooring	Resilient flooring
Interior glazed partition	Glazing Panel
	Hollow Structural Steel
	Aluminum Extrusion
Curtain wall	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