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A Grander View

The Enermodal Engineering Office Building
Kitchener, ON

An Environmental Building Declaration According to EN 15978 Standard

Photo courtesy Enermodal Engineering

Prepared By:
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Executive Summary

The purpose of this work is to declare the environmental performance of the *Enermodal Engineering Office Building* according to the requirements of the new Committee for European Standardization (CEN) *EN 15978:2011* standard. EN 15978 specifies a life cycle assessment (LCA)-based calculation and reporting method for buildings; the intent of this work is to apply the standard to a North American context in order to demonstrate its content and utility as a standardized and transparent reporting format for environmental declarations of buildings.

A Grander View, the new headquarters of Enermodal Engineering Ltd., has 2043 m^2 of floor space on three storeys. It is predicted to use 65 kWh/m^2 of operating energy per year, an 84% reduction relative to the Canadian average, and is also predicted to use 82% less water by way of various reduction and conservation strategies. The effects of material use were also considered during design, including efficient footprint and structural span design, and the use of recycled, reused and locally sourced materials. These design characteristics enabled *A Grander View* to be the first building to receive three LEED Platinum certifications.

The scope of building materials assessed includes envelope and structural elements, as well as interior partitions and screen glass, and gypsum wallboard finishes. In terms of operating energy use, the assessment includes heating, ventilation, air-conditioning (HVAC), lighting and plug loads. Operating water use was also considered.

50-year Cradle-to-Grave Building Effects Results

Environmental Impacts		
Global warming potential	3.04E+06	kg CO_2 eq.
Ozone depletion potential	8.93E-03	kg CFC-11 eq.
Acidification potential	1.38E+06	moles of H+ eq.
Eutrophication potential	1.43E+03	kg N eq.
Photochemical smog potential	2.06E+05	kg O_3 eq.
Abiotic resource depletion potential, elements	xx	kg Sb eq.
Fossil fuel use	4.14E+07	MJ
Human health criteria pollutants	1.24E+04	kg PM10 eq.
Resource Use		
Renewable primary energy use, excluding feedstock	7.59E+06	MJ
Renewable primary energy use, feedstock	2.14E+05	MJ
Non-renewable primary energy use, excluding feedstock	1.05E+08	MJ
Non-renewable primary energy use, feedstock	1.79E+06	MJ
Secondary material use	1.58E+05	kg
Renewable secondary fuel use	xx	MJ
Non-renewable secondary fuel use	xx	MJ
Water use	1.61E+04	m^3
Waste Categories		
Non hazardous waste to disposal	1.54E+06	kg
Hazardous waste to disposal	xx	kg
Radioactive waste	xx	kg
Output Flows		
Components for reuse	0.00E+00	kg
Material for recycling	1.38E+06	kg
Material for energy recovery	0.00E+00	kg
Exported energy	0.00E+00	MJ

note: "xx" means the indicator was not assessed

The life cycle of a building according to EN 15978 is comprised of Product, Construction Process, Use, and End of Life stages. This assessment reports results for 13 of the 16 information modules (labeled as A1 through C4 in EN 15978) covering the complete life cycle system boundary, along with supplemental information pertaining to benefits beyond the system boundary. The scenarios used to model the life cycle are described herein and include aspects related to construction waste, materials transportation, building maintenance and operation, and end of life.

Three sources of life cycle inventory (LCI) data were used to construct the declaration: the Athena LCI Database is the source for material and operating energy 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 material transportation. The Ecoinvent LCI Database was used for processes not available in either Athena or US LCI databases, in particular water treatment facility and landfill effects. The assessment reports 18 of the 23 environmental indicators considered by EN 15978, along with human health criteria pollutants. Environmental impacts were calculated according to the USA EPA's TRACI life cycle impact assessment (LCIA) methodology and energy resource use according to cumulative energy demand (CED) methodology. Other indicators were calculated by tracking LCI and material use flows.

The declaration reports the 18 indicators by information module. A summary of cradle-to-grave effects over the building's 50-year service life is shown above. A supplementary report comparing this "as-built" design to a typical contemporary design of the same building was also prepared again using EN 15978 as the basis for assessment.

Author of this report:
Matt Bowick, Senior Research Associate, Athena Sustainable Materials Institute. May 2013.

Internal verifier of the declaration:
Jamie Meil, Managing Director, Athena Sustainable Materials Institute.

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1.0 General Information on the Assessment

1.1 Purpose of the Assessment

The purpose of this work is to declare the environmental performance of the *Enermodal Engineering Office Building* according the requirements of the new Committee for European Standardization (CEN) *EN 15978:2011* standard (Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method). EN 15978 specifies a life cycle assessment (LCA) based calculation and reporting method for buildings. The intent of this work is to apply the standard to a North American context in order to demonstrate its content and utility as a standardized and transparent reporting format for environmental declarations of buildings. This report may be subsequently used for marketing and educational purposes. The applied methodology will also provide a gap and issues roadmap for the further development of the Athena Institute's *Impact Estimator for Buildings* software and database.

1.2 Identification of the Building

A Grander View (see Figures 1 and 2), the new headquarters of Enermodal Engineering Ltd., is located at 582 Lancaster West, in Kitchener Ontario, and was completed in October 2009. The building has 2043 m^2 of floor space on three storeys. It is predicted to use 65 kWh/m^2 of operating energy per year, an 84% reduction relative to the Canadian average of 400 kWh/m^2, and is also predicted to use 82% less water by way of various reduction and conservation strategies. The effects of material use were also considered during the design process, including efficient footprint and structural span design, and the use of recycled, reused and locally sourced materials. These design characteristics enabled A Grander View to be the first building to receive three LEED Platinum certifications: LEED-NC (New Construction), LEED-CI (Commercial Interiors), and LEED-EBOM (Existing Buildings: Operations and Maintenance).

1.3 Other Assessment Information

Table 1 provides a summary of some pertinent assessment information, in accordance with EN 15978.

Table 1: Assessment Information Summary

Client for assessment	Enermodal Engineering Ltd.
Assessor	Matt Bowick (M.A.Sc.), Senior Research Associate at the Athena Sustainable Materials Institute
Assessment method	TRACI 2 version 4.0, Cumulative Energy Demand (CED)
Assessment timing	3 years post-occupancy
Period of validity	5 years
Date of assessment	December 2012
Internal Verifier	Jamie Meil (M.Sc.), Managing Director at the Athena Sustainable Materials Institute

Statement regarding verification of this assessment:
The verifier has determined that this LCA study meets the requirements for methodology, data, and reporting in EN 15978, and is consistent with its principles.

2.0 General Information on the Object of Assessment

2.1 Functional Equivalent

EN 15978 defines a functional equivalent as "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". The functional equivalent of the Enermodal Engineering Office Building includes the characteristics noted in Table 2.

Table 2: Enermodal Engineering Office Building Functional Equivalent

Building type	low-rise, owner occupied office building
Technical and functional requirements	2006 Ontario Building Code and 1997 Model National Energy Code for Buildings
Pattern of use	typical office space use for 85 occupants
Required service life	50 years

2.2 Reference Study Period

The reference study period of the assessment is the same as the required service life of 50 years.

2.3 Object of Assessment Scope

The object of assessment is the Enermodal Engineering Office Building and only includes elements contained within the building footprint. Exterior features, such as the parking lot and landscaping are not included. The scope of building materials assessed includes envelope and structural elements, as well as interior partitions and screen glass, and gypsum board finishes. This scope is equivalent to Major Group Elements A1 SUBSTRUCTURE, A2 STRUCTURE, A3 EXTERIOR ENCLOSURE, B1 PARTITIONS, as defined by the Canadian Institute of Quantity Surveyors (CIQS) Elemental Format. Other building elements were not included in assessment scope due to assessment resource constraints and/or data limitations

In terms of operating energy use, the object of assessment includes heating, ventilation, air-conditioning (HVAC) and lighting building integrated systems, as well as plug loads (non-building integrated systems). Only building integrated operating water use systems such as faucets, toilets, and showers are considered. The effects of occupant compost, recycling, and municipal waste generation are not within the scope of EN 15978 and therefore not considered.

2.4 Building Description

The ground floor structure is a 100 mm slab on grade; above grade floors and roof structure are 305 mm hollow-core panels that span the 12 m building width, a strategy employed to minimize interior structure. The hollow-core panels are supported by 388 mm insulated concrete form (ICF) walls (254mm concrete) at the perimeter and steel framing at interior openings. The foundation is comprised of perimeter ICF walls supported by strip footings;

interior steel columns are supported by concrete piers and spread footings. Staircases are structural steel with concrete topping and guardrails are generally tempered glass with steel support.

Figure 1: Exterior of the Enermodal Engineering Office Building

In terms of building envelope, the perimeter ICF walls have a total of 134 mm of expanded polystyrene insulation (EPS), are clad with a mix of natural stone veneer (reclaimed), wood and metal siding, and exterior insulated finish system (EIFS) panels, and have a gypsum wallboard interior finish. Use of ICF walls greatly reduces thermal bridging across the wall assembly and helps provides an airtight seal; a blower door test conducted on A Grander View revealed an air change per hour (ACH) rate of less than 1 at 50 Pa pressure. The building has a window-to-wall ratio of approximately 0.28 and is glazed with triple-pane fiberglass frame units and a curtain wall at the main entrance. The slab on grade is insulated with 50 mm of extruded polystyrene (XPS) and roof assembly is a single ply TPO membrane assembly with 100 mm of polyisocynaurate insulation. Finally, the interior partition walls are a combination of light gauge steel studs with sound attenuation insulation and gypsum wallboard, and screen glass. Other finish materials such as flooring are not in the scope of the assessment and therefore not described herein.

The building is heated and cooled with three rooftop air-source condensing units that provide heat in weather as low -25°C without supplemental electric heating. One unit has heating and cooling design capacities of 19.2 kW (COP = 1.7) and 23.2 kW (COP = 4.1), respectively, while the other two units have design capacities of 26 kW (COP = 1.59) and 30.9 kW (COP = 3.68), respectively. The condensing units (one per floor) are connected to 60 fan coil units located throughout the building with a refrigerant-filled pipe network. The refrigerant is sent through the piping by variable flow compressors that can work at very low speeds, allowing the system to run at lower energy. The "multi-split" fan coil system allows occupants to adjust temperature and humidity more precisely throughout the building. Space cooling energy needs are reduced by natural ventilation: a louver at the top of the atrium and nearby operable windows expel hot interior air from the building. The system is automated according to sensors that monitor indoor and outdoor temperatures. Space cooling demand is also reduced by removing the computer server room heat with an air-to-water heat pump unit (average design COP = 3.5), which in turn supplies the building's hot water needs.

Prior to entering the building, incoming air for ventilation passes through concrete tubes located underground. Due to ambient earth temperatures, the tubes provide energy savings by pre-heating air in winter and pre-cooling it in summer. Similarly, the incoming air is also pre-heated or pre-cooled by heat and moisture exchange with the exhaust air by way of energy recovery ventilators (ERVs). CO_2 sensors throughout the building allow the ventilation rate to be adjusted to meet the occupancy requirement, i.e. the more people in a room, the more ventilation is provided to it. Daylighting is the primary source of light for the building with premium efficiency T8 lamps and ballasts, and compact fluorescent pendants providing back-up artificial light. The mix of natural and artificial light is regulated by daylighting sensors and occupancy sensors additionally turn off lights when an area is unoccupied.

A Grander View employs several strategies to reduce potable water consumption. The building uses no water for landscaping irrigation and generally uses water efficient fixtures and appliances. A 30 m^3 underground precast concrete grey water cistern stores rainwater from rooftop catchment to flush toilets. During summer months condensate from the three heat pumps provides additional grey water for toilets and is predicted to produce up to 20L/hr. When these systems are not sufficient for demand, municipal water connected directly to the fixtures is used.

Figure 2: Interior of the Enermodal Engineering Office Building

3.0 Statement of Boundaries and Scenarios Used in the Assessment

3.1 System Boundary

EN 15978 defines the system boundary of a building life cycle according to the format shown in Figure 3. The life cycle includes four stages (Product, Construction Process, Use, and End of Life) composed of information modules labeled A1 through C4. Additionally, benefits or loads beyond the building life cycle system boundary (e.g. net benefit of recycling materials at end of life) are allotted to module D. This structure provides a consistent and transparent reporting format for building assessments and is consistent with the structure of environmental product declarations (EPDs) produced in conformance with the standard EN 15804:2012 (Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products).

Figure 3: EN 15978 Building LCA Life Cycle Stages and Modules (study scope shown grey)

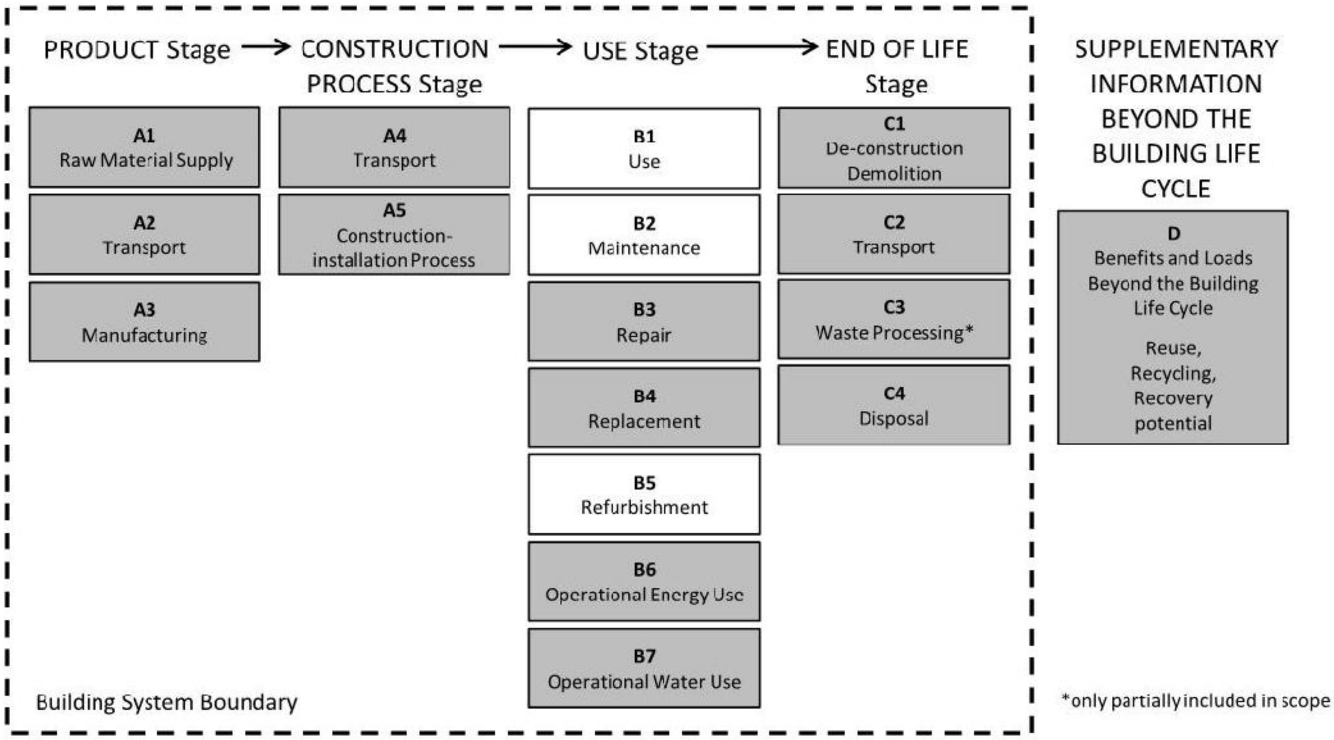


Table 3 is a summary of which information modules are included in the assessment, along with a brief description of the effects captured by each. The modules included in scope are additionally shown infilled grey in Figure 3. Four of the modules were not assessed, or only partially assessed, for the following reasons:

- **B1:** there is currently insufficient consensus in terms of LCA methodology and data to practically quantify these effects for all products used in the building.
- **B2:** much of this module pertains to cleaning product use, which is in part dependant on flooring choice - materials outside the scope of the object of assessment.
- **B5:** there is no planned refurbishment at this time and no available data on typical refurbishment activities for this type of building.
- **C3:** waste processing facility environmental data is currently not available. The assessment does include the total output flows of materials sent to waste processing.

3.2 Scenarios for Defining the Building Life Cycle

Due to the fact that [1] not all information is practically available to the assessor and [2] buildings have long and uncertain services lives, scenarios (i.e. assumptions) are required to provide a complete description of the building. This section describes the scenarios assumed that are relevant to the object of assessment scope and its system boundary. The scenarios are consistent with the assessment system boundary noted in Section 3.1 and are based on current practice.

Table 3: 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	all transportation up to manufacturing plant gate
A3	Manufacturing	Y	manufacture of raw materials into products
A4	Transport	Y	transportation of materials and construction equipment to site
A5	Construction-installation process	Y	construction equipment energy use, and production, transportation and waste management of material lost during construction
B1	Installed product in use	N	n/a
B2	Maintenance	N	n/a
B3	Repair	Y	all product, construction process, and end of life related activities related to repairing building components during use
B4	Replacement	Y	all product, construction process, and end of life related activities related to replacing building components during use
B5	Refurbishment	N	n/a
B6	Operational energy use	Y	energy production, transportation and use
B7	Operational water use	Y	water and wastewater treatment facilities
C1	De-construction demolition	Y	demolition equipment energy use, and on-site particulate matter emissions
C2	Transport	Y	transportation of recovered materials from site to waste processing plant and waste to disposal facility
C3	Waste Processing	Y/N	only output flows of materials sent to waste processing included
C4	Disposal	Y	disposal facility equipment energy use and site effects
D	Benefits and loads beyond the system boundary	Y	avoided emissions due to recovered materials and energy used in lieu of conventional sources

3.2.1 Required Service Life

The reference service life is assumed to be 50 years, as per Enermodal Engineering's *Building Durability Plan*. The plan was produced in accordance with CSA S478-95 standard and LEED Canada-NC v1.1 Material and Resources (MR) credit 8 (Durable Buildings).

Table 4: Transportation and Construction Waste Factor Scenarios

Material	Distance Transported to Site (km)				Construction Waste Factor
	Rail	Road	Barge	Ocean	
#15 Organic Felt	0	125	0	0	1.14
5/8" Fire-Rated Type X Gypsum Board	0	193	0	0	1.10
6 mil Polyethylene	0	76	0	0	1.02
Air Barrier	0	76	0	0	1.02
Aluminum	0	1,165	0	0	1.00
Ballast (aggregate stone)	0	60	0	0	1.05
Batt Fiberglass	0	100	0	0	1.05
Batt Rockwool	0	104	0	0	1.05
Cedar Wood Bevel Siding	0	377	0	0	1.10
Cold Rolled Sheet	0	120	0	0	1.01
Commercial (26 ga.) Steel Cladding	0	125	0	0	1.10
Concrete 20 MPa (flyash 25%)	0	60	0	0	1.05
Concrete 30 MPa (flyash 25%)	0	60	0	0	1.05
Concrete 60 MPa (flyash av)	0	60	0	0	1.05
EPDM membrane (black, 60 mil)	0	1,110	0	0	1.03
Expanded Polystyrene	0	111	0	0	1.05
Extruded Polystyrene	0	100	0	0	1.05
Fiber Cement	656	73	0	0	1.10
Galvanized Decking	0	120	0	0	1.01
Galvanized Sheet	0	120	0	0	1.01
Galvanized Studs	0	120	0	0	1.01
Glazing Panel	0	500	0	0	1.00
Hollow Structural Steel	0	120	0	0	1.01
Joint Compound	0	412	0	0	1.07
Large Dimension Softwood Lumber	3,980	60	0	0	1.05
Low E Tin Argon Filled Glazing	0	500	0	0	1.01
Modified Bitumen membrane	0	390	0	0	1.03
Mortar	0	60	0	0	1.15
Nails	0	60	0	0	1.03
Natural Stone	0	500	0	0	1.05
Open Web Joists	0	60	0	0	1.01
Paper Tape	0	412	0	0	1.05
Polyiso Foam Board (unfaced)	0	227	0	0	1.05
Polypropylene	0	76	0	0	1.02
Precast Concrete	0	60	0	0	1.00
PVC	0	40	0	0	1.00
PVC Membrane 48 mil	0	951	0	0	1.03
Rebar, Rod, Light Sections	0	60	0	0	1.03
Screws Nuts & Bolts	0	60	0	0	1.03
Small Dimension Softwood Lumber	0	397	0	0	1.08
Softwood Plywood	3,980	60	0	0	1.05
Solvent Based Alkyd Paint	0	110	0	0	1.02
Water Based Latex Paint	0	110	0	0	1.02
Welded Wire Mesh / Ladder Wire	0	120	0	0	1.02
Wide Flange Sections	0	120	0	0	1.01

3.2.2 Transportation

The assumed plant-to-site materials transportation scenarios presented in Table 4 are estimated values from the *Athena Transportation Database* for the Toronto, Ontario location. Toronto is approximately 100 km from the study building (Kitchener, Ontario). Rail and road transport is assumed to be diesel fuelled.

At the end of the building's 50-year service life, all landfilled materials are assumed to be transported 80 km by diesel truck to the disposal facility. This estimated distance and mode is taken from the *Athena Transportation Database* for the Toronto location. Recycled materials are assumed to be transported 30 km to a waste processing facility or other construction site.

3.2.3 On-site Construction Waste

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 final building. The assessment accounts for these additional quantities by multiplying materials required by the building at initial construction, and during repair and replacement, by Waste Factors. The assumed scenarios shown in Table 4 are estimates taken from the *Athena Construction Waste Factor Database*.

3.2.4 Repair and Replacement

Repair and replacement typically involves periodic tasks (i.e. material replacements) to ensure the continued functional performance of the building. This assessment follows the methodology used by the Impact Estimator for Buildings software to calculate the number of times a task occurs over the lifetime of the building:

$N_x = (S - F_x) / F_x$ (1)

where,

N_x	is the number of times task x occurs
S	is the building service life (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 (1) deviates from the methodology outlined in EN 15978. The standard requires that [1] only whole replacements 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 the opinion of the Athena Sustainable Materials Institute that this causes inconsistency between assessments.

Equation (2) was used to calculate the total material quantities being replaced over the building lifetime:

$Q_{x,y} = N_x \; M_y \, P_{x,y}$ (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

Tables 5 and 6 summarize the Repair and Replacement module scenarios assumed, taken from the following data sources:

1) Whitestone Research's *Maintenance and Repair Cost Database*
2) Athena Institute report *Maintenance, Repair, and Replacement Effects for Building Envelope Materials*
3) Estimated from product literature or other sources

Sources 1 and 2 are estimates based on industry surveying and professional judgment.

Table 5: Repair Module Scenarios

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Source #
Slab on grade	Concrete 20 MPa (flyash 25%)	15	2	1
	Extruded Polystyrene	15	2	1
Claddings	Fiber Cement	25	2	1
	Commercial (26 ga.) Steel Cladding	25	2	1
	Cedar Wood Bevel Siding	25	2	1
	EIFS panels	25	2	1
Foundation wall parge coat	Mortar	15	2	1
Natural stone veneer mortar	Mortar	25	15	2
Gypsum wallboard	5/8" Fire-Rated Type X Gypsum Board	20	2	1
	Joint Compound	20	2	1
	Nails	20	2	1
	Paper Tape	20	2	1
	Water Based Latex Paint	20	2	1
Windows	Low E Tin Argon Filled Glazing	1	3	2
Curtain wall	Aluminum	35	100	2
	EPDM membrane (black, 60 mil)	35	100	2
	Glazing Panel	1	3	2
	Screws Nuts & Bolts	35	100	2
	Galvanized Sheet	35	100	2
	Batt Fiberglass	35	10	2
Hollow core floor topping	Concrete 20 MPa (flyash 25%)	15	2	1
Stair topping	Concrete 20 MPa (flyash 25%)	15	2	1
Stair and floor opening gards	Glazing Panel	15	2	1
Parapet flashing	Aluminum	1	1.5	2
Roof decking	Small Dimension Softwood Lumber, kiln-dried	25	2	1
Roof envelope	6 mil Polyethylene	1	1.5	2
	Galvanized Sheet	1	1.5	2
	Nails	1	1.5	2
	Foam Polyisocyanurate	1	1.5	2
	PVC Membrane 48 mil	1	1.5	2
	Small Dimension Softwood Lumber, kiln-dried	1	1.5	2
	Softwood Plywood	1	1.5	2

The reporting format and calculation methodology of the sourced task frequencies (F_x) and material use %'s ($P_{x,y}$) are not compliant with ISO standards 15686-1 (Buildings and constructed assets - Service life planning - General principles and framework) and 15686-8 (Buildings and constructed assets - Service life planning - Reference service life and service-life estimation), as required by EN 15978. Nevertheless, it is the opinion of the Athena Institute that until service life planning is a more established practice in North America, the sources from which the scenarios were developed are of sufficient quality for this building assessment.

Table 6: Replacement Module Scenarios

Assembly/Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Source #
Claddings	Commercial (26 ga.) Steel Cladding	30	100	2
	Cedar Wood Bevel Siding	25	100	2
	EIFS panels	35	100	3
Gypsum wallboard	Water Based Latex Paint	5	100	2
Windows	Low E Tin Argon Filled Glazing	18	100	2
	PVC	18	100	2
	Nails	18	100	2
	Aluminum	18	100	2
	EPDM membrane (black, 60 mil)	18	100	2
Parapet flashing	Aluminum	15	100	2
Roof wood deck	Small Dimension Softwood Lumber, kiln-dried	20	100	3
Roof envelope	6 mil Polyethylene	15	100	2
	Galvanized Sheet	15	100	2
	Nails	15	100	2
	Foam Polyisocyanurate	15	80	2
	PVC Membrane 48 mil	15	80	2
	Small Dimension Softwood Lumber, kiln-dried	15	100	2
	Softwood Plywood	15	100	2
	Ballast (aggregate stone)	15	80	2

3.2.5 Operating Energy

The energy use scenario comes from actual measured consumption for the period of January 1, 2010 to December 31, 2010. It is assumed that this energy consumption represents a typical annual demand over the 50 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 50-year building service life. Similarly, it is assumed that purchased energy sources do not markedly change over the modelled service life (e.g., purchased electricity is assumed to be generated using the same energy source mix).

3.2.6 Operating Water

The water use scenario comes from actual measured consumption. Wastewater flows are assumed to be equal to the demand since there is no water used for irrigation. Water system technologies and their rate of use are assumed not to change over the 50-year building service life.

3.2.7 End of Life

End of Life stage modules require assumptions regarding the fate of the materials post building use. There is currently little construction sector statistical information on this topic to develop scenarios. The assumed scenarios presented in Table 7 are estimates taken from the Athena Institute report titled *Life Cycle Assessment of Precast Concrete Commercial Buildings: Cradle-to-Grave*, prepared for the Canadian Precast/Prestressed Concrete Institute. The one exception to this is that the scenario for concrete, brick, and natural stone is from the EPA's WARM program documentation.

Materials sent to landfill would currently be most likely sent to the Region of Waterloo waste management facility. The facility does not incinerate any of its waste, consistent with the assumed scenarios.

Table 7: End of Life Stage Scenarios

Material	Landfilled	Incinerated	Reused	Recycled	Energy Recovery
Steel cladding and structural members	2%	0%	0%	98%	0%
Steel reinforcing	30%	0%	0%	70%	0%
Aluminum	5%	0%	0%	95%	0%
Gypsum wallboard	85%	0%	0%	15%	0%
Concrete, brick, and natural stone	45%	0%	0%	55%	0%
All other materials	100%	0%	0%	0%	0%

3.2.8 Benefits Beyond the System Boundary

According to EN 15978, module D quantifies the future potential net benefit of materials and energy sources recovered from the object of assessment and exiting the system boundary. Generally, these output flows are assumed to substitute materials or energy production from average existing technology or current practice. The following are the assumptions used to calculate the net future potential avoided emissions resulting from the recovered materials noted in Section 3.2.7:

- **Recycled steel and aluminum** materials substitute for primary metal production. The avoided emissions therefore are the difference between primary and secondary metals production (i.e. the "scrap value").
- **Recycled concrete, brick, and natural stone** materials are crushed on-site and substitute for aggregate. The avoided emissions are therefore the difference between the effects primary aggregate production (i.e. quarrying and crushing) and crushing of concrete, brick, and natural stone on-site.
- **Recycled gypsum wallboard** is crushed at a waste processing facility and substitutes primary gypsum production. The avoided emissions are therefore the difference between the effects primary gypsum production (i.e. mining and crushing) and crushing of gypsum wallboard.

4.0 Environmental Data

4.1 Data Sources

Building LCA typically draws on environmental product declaration (EPD) and/or life cycle inventory (LCI) environmental data sources. The use of EPDs in North America is in its infancy at present. The assessment does not draw on EPDs as a source of data since [1] currently few building material EPDs exist in North America, [2] there is a general lack of consistency between EPDs of different product categories and [3] North America has not adopted EN 15804 and therefore EPDs don't include all the environmental indicators required by EN 15978. For these reasons, the study draws exclusively on three LCI data sources:

- the Athena LCI Database (http://www.athenasmi.org/our-software-data/lca-databases/)
- the US LCI Database (http://www.nrel.gov/lci/)
- the Ecoinvent LCI Database (http://www.ecoinvent.ch/)

Table 8 presents a summary of which LCI data sources were used for the various information modules considered in the assessment. In general, the Athena LCI Database is the source for material and operating energy 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 water treatment facility and landfill effects. Since Ecoinvent data is European in context, the datasets used were adjusted to better reflect a Canadian context, as outlined in Section 4.2.

Table 8: Data Sources Summary

LCI Data	Information Modules	Database Source	Time Frame	Geographical Represent-ativeness	Technological Represent-ativeness
Common primary fossil fuels (including pre-combustion)	All	US LCI	2004-2008	Canada	Average
Electricity generation and delivery	All	US LCI	2007	Ontario	Average
Transportation	A2, A4, B3, B4, C2	US LCI	2004-2008	Canada	Average
Building materials	A1, A3, A5, B3, B4, C1, D	Athena LCI	2002 - 2012	Canada and Ontario	Average
Water and wastewater treatment	B6	Ecoinvent LCI	2005, 2009	Switzerland, adjusted to Canada and Ontario	Average
Particulate emissions from demolition/deconstruction	C1	Ecoinvent LCI	2003	Switzerland	Average
Landfill	C4	Ecoinvent LCI	2003	Switzerland, adjusted to Canada and Ontario	Average

4.2 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 in order to remain consistent with current North American LCA practice

LCI data for some of the building materials was unavailable. In order to include these materials in the scope of assessment, materials from the Athena LCI Database deemed to most closely estimate their environmental profile was 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. For example, the drainage board (22 mil polyethylene, modeled as 6 mil polyethylene) takeoffs were multiplied by a factor of 22/6 = 3.67 to account for differences in product thickness. Table 9 is a summary of materials that were substituted.

Table 9: LCI Data Substitutions

Material	Athena LCI Database Substitution(s)
Peel and stick membrane	6 mil Polyethylene, Modified Bitumen membrane
Drainage board	6 mil Polyethylene
TPO roof membrane	PVC Membrane 48 mil
Cedar roof decking	Small Dimension Softwood Lumber, kiln-dried
Fibreglass window frames	PVC
Metal cladding	Commercial (26 ga.) Steel Cladding
Cedar cladding	Cedar Wood Bevel Siding
EIFS panels	Water Based Latex Paint, Mortar, Fibreglass Batt, Expanded Polystyrene

4.3 Data Quality

Precision: all LCI data sources used were compiled in accordance with ISO 14040/14044 procedures and requirements. The data adjustments and substitutions noted in Section 4.2 introduce inaccuracies; the sensitivity of whole building results with respect to changes in some of these elements is investigated in Section 7.2.

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 modified to align with Athena/US LCI Database system boundaries.

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

Representativeness:

- Time related coverage **-** validation of data is not older than 10 years, as required by EN 15978.
- Geographical coverage **-** at minimum Canada and representative of the region (Ontario) where the building is located
- Technological coverage - average, reflecting the physical reality of the products found in the building. The wastewater treatment plant data used considers tertiary treatment that includes phosphate precipitation; the wastewater treatment plant in Kitchener has a similar level of treatment.

5.0 List of Indicators Used for Assessment and Expression of Results

A summary of the environmental indicator results required by EN 15978, with which are included in the assessment, is presented in Table 10. 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 the EPA's TRACI 2, version 4 (http://www.epa.gov/nrmrl/std/traci/traci.html) life cycle impact assessment (LCIA) methodology. TRACI provides a North American context for the supported measures and results in some of the indicator units being different than those required by EN 15978. This has been deemed acceptable for this study since North American adoption of EN 15978 would inevitably be structured on the use of TRACI as the accepted LCIA methodology. The human health criteria pollutants indicator is not required by EN 15978 but has been included in the assessment as additional information.

Energy resource use was evaluated according to Cumulative Energy Demand (CED) methodology (updated in 2010). All other indicators considered were evaluated by compiling either LCI flows (e.g. water use) or material usage (e.g. materials for recycling) over the building life cycle.

Table 10: Environmental Indicator Summary

Environmental Indicator	Unit	Included?
Environmental Impacts		
Global warming potential	kg CO_2 eq.	Y
Ozone depletion potential	kg CFC-11 eq.	Y
Acidification potential	moles of H+ eq.	Y
Eutrophication potential	kg N eq.	Y
Photochemical smog potential	kg O_3 eq.	Y
Abiotic resource depletion potential, elements	kg Sb eq.	N
Fossil fuel use	MJ	Y
Human health criteria pollutants (not in scope of EN 15978)	kg PM10 eq.	Y
Resource Use		
Renewable primary energy use, excluding feedstock	MJ	Y
Renewable primary energy use, feedstock	MJ	Y
Non-renewable primary energy use, excluding feedstock	MJ	Y
Non-renewable primary energy use, feedstock	MJ	Y
Secondary material use	kg	Y
Renewable secondary fuel use	MJ	N
Non-renewable secondary fuel use	MJ	N
Water use	m^3	Y
Waste Categories		
Non hazardous waste to disposal	kg	Y
Hazardous waste to disposal	kg	N
Radioactive waste	kg	N
Output Flows		
Components for reuse	kg	Y
Material for recycling	kg	Y
Material for energy recovery	kg	Y
Exported energy	MJ	Y

6.0 Model Development

The Athena Institute received a full set of architectural, structural, and mechanical/electrical drawings from Enermodal Engineering Ltd. The drawings were used to establish the construction assemblies and geometry required to calculate material quantities for each life cycle stage considered. Material takeoffs were calculated using a combination of the Athena Impact Estimator for Buildings software and a Microsoft Excel-based program developed by the Athena Institute.

Table 11: Life Cycle Bill of Materials

Material	Quantity	Unit
#15 Organic Felt	852	m^2
5/8" Fire-Rated Type X Gypsum Board	4,571	m^2
6 mil Polyethylene	5,855	m^2
Air Barrier	650	m^2
Aluminum	10.1	Tonnes
Ballast (aggregate stone)	315,982	kg
Batt Fiberglass	1,074	m^2 (25mm)
Batt Rockwool	5,044	m^2 (25mm)
Cedar Wood Bevel Siding	596	m^2
Cold Rolled Sheet	3.33	Tonnes
Commercial (26 ga.) Steel Cladding	1,274	m^3
Concrete 20 MPa (flyash av)	182	m^3
Concrete 30 MPa (flyash av)	530	m^3
EPDM membrane (black, 60 mil)	813	kg
Expanded Polystyrene	926	m^2 (25mm)
Extruded Polystyrene	3,315	m^2 (25mm)
Fiber Cement	146	m^2
Galvanized Decking	0.195	Tonnes
Galvanized Sheet	2.08	Tonnes
Galvanized Studs	7.50	Tonnes
Glazing Panel	12.9	Tonnes
Hollow Structural Steel	5.61	Tonnes
Joint Compound	4.56	Tonnes
Low E Tin Glazing	1,399	
Modified Bitumen membrane	625	kg
Mortar	7.55	m^3
Nails	1.29	Tonnes
Natural Stone	224.11	m^2
Open Web Joists	0.079	Tonnes
Paper Tape	0.066	Tonnes
Polyiso Foam Board (unfaced)	5,153	m^2 (25mm)
Precast Concrete	277	m^3
PVC	4,126	kg
PVC Membrane 48 mil	4,271	kg
Rebar, Rod, Light Sections	24.7	Tonnes
Screws Nuts & Bolts	2.50	Tonnes
Small Dimension Softwood Lumber, kiln-dried	14.2	m^3
Softwood Plywood	731	m^2 (9mm)
Solvent Based Alkyd Paint	3.54	L
Water Based Latex Paint	11,044	L
Welded Wire Mesh / Ladder Wire	3.56	Tonnes

Wide Flange Sections	15.4	Tonnes

Enermodal Engineering provided the Athena Institute with annual operating energy and water use. The resulting 50-year life cycle bill of materials (BOM), and annual operating energy and water use are presented in Tables 11 and 12. The environmental indicator results presented in Section 7 were calculated based on the model inputs noted above, using [1] the Athena Impact Estimator for Buildings v4.2, [2] SimaPro v7.3, and [3] an Excel-based program developed by the Athena Institute.

Table 12: Life Cycle Operating Energy and Water Use

Item	Building Integrated Systems	Non Building Integrated Systems	Total
Electricity (kWh)	5,786,600	1,827,350	7,613,950
Water (m^3)	11,350	0	11,350
Wastewater (m^3)	17,700	0	17,700

7.0 Communication of Assessment Results

7.1 Life Cycle Results

50-year life cycle results for the Enermodal Engineering Office Building are presented in Tables 13 and 14, and Figures 4 and 5 show the contributions of the various information modules to the total life cycle results. Modules A1 and A3 are combined due to the granularity of LCI data sources used. As per EN 15978, operational energy use from building-integrated and non-building-integrated systems have been presented separately as modules B6a and B6b, respectively. As previously noted, building integrated systems include HVAC, hot water, and lighting, and plug loads make up the non-building integrated systems.

N.B. Information modules and environmental indicators not assessed have been denoted with “xx”.

Table 13: Life Cycle Results, by information module

Environmental Indicators	Unit	PRODUCT stage		CONSTRUCTION PROCESS stage		USE stage							
		Raw Material Supply and Manufacturing	Transport	Transport	Construction Installation Process	Use of Products	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use: Building Integrated Systems	Operational Energy Use: Non Building Integrated Systems	Operational Water Use
		A1/A3	A2	A4	A5	B1	B2	B3	B4	B5	B6a	B6b	B7
Environmental Impacts													
Global warming potential	kg CO_2 eq.	4.81E+05	1.11E+04	1.73E+04	2.09E+04	xx	xx	4.54E+04	1.99E+05	xx	1.69E+06	5.34E+05	8.67E+03
Ozone depletion potential	kg CFC-11 eq.	3.73E-03	4.46E-07	6.88E-07	1.60E-04	xx	xx	5.07E-04	3.62E-03	xx	4.53E-05	1.43E-05	3.38E-04
Acidification potential	moles of H+ eq.	1.72E+05	3.66E+03	5.33E+03	2.26E+04	xx	xx	2.23E+04	1.12E+05	xx	7.82E+05	2.47E+05	3.31E+03
Eutrophication potential	kg N eq.	2.18E+02	3.98E+00	5.80E+00	2.59E+01	xx	xx	6.30E+01	3.10E+02	xx	2.05E+02	6.47E+01	5.26E+02
Photochemical smog potential	kg O_3 eq.	3.23E+04	1.97E+03	2.83E+03	1.23E+04	xx	xx	5.03E+03	1.58E+04	xx	1.01E+05	3.20E+04	5.23E+02
Abiotic resource depletion potential, elements	kg Sb eq.	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Fossil fuel use	MJ	5.09E+06	1.60E+05	2.26E+05	2.49E+05	xx	xx	3.95E+05	3.04E+06	xx	2.42E+07	7.63E+06	4.42E+04
Human health criteria pollutants	kg PM10 eq.	4.53E+03	4.76E+00	6.92E+00	1.52E+02	xx	xx	1.15E+03	3.48E+03	xx	2.12E+03	6.69E+02	7.07E+00
Resource Use													
Renewable primary energy use, excluding feedstock	MJ	4.67E+05	6.58E+01	1.01E+02	6.13E+03	xx	xx	4.84E+04	2.68E+05	xx	5.16E+06	1.63E+06	1.15E+04
Renewable primary energy use, feedstock	MJ	7.52E+04	0.00E+00	0.00E+00	5.65E+03	xx	xx	8.64E+03	1.25E+05	xx	0.00E+00	0.00E+00	0.00E+00
Non-renewable primary energy use, excluding feedstock	MJ	1.59E+07	1.61E+05	2.27E+05	2.40E+05	xx	xx	1.41E+06	9.16E+06	xx	5.91E+07	1.87E+07	1.00E+05
Non-renewable primary energy use, feedstock	MJ	1.24E+06	0.00E+00	0.00E+00	3.20E+04	xx	xx	3.71E+04	4.77E+05	xx	0.00E+00	0.00E+00	0.00E+00
Secondary material use	kg	1.54E+05	0.00E+00	0.00E+00	0.00E+00	xx	xx	1.43E+03	3.28E+03	xx	0.00E+00	0.00E+00	0.00E+00
Renewable secondary fuel use	MJ	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Non-renewable secondary fuel use	MJ	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Water use	m^3	2.52E+03	0.00E+00	0.00E+00	1.50E-01	xx	xx	9.74E+01	6.14E+02	xx	0.00E+00	0.00E+00	1.28E+04
Waste Categories													
Non hazardous waste to disposal	kg	9.24E+04	1.04E+02	1.61E+02	4.73E+04	xx	xx	3.27E+04	8.05E+04	xx	5.22E+04	1.65E+04	6.63E+02
Hazardous waste to disposal	kg	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Radioactive waste	kg	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Output Flows													
Components for reuse	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	xx	xx	0.00E+00	0.00E+00	xx	0.00E+00	0.00E+00	0.00E+00
Material for recycling	kg	0.00E+00	0.00E+00	0.00E+00	4.64E+04	xx	xx	9.83E+03	1.56E+04	xx	0.00E+00	0.00E+00	0.00E+00
Material for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	xx	xx	0.00E+00	0.00E+00	xx	0.00E+00	0.00E+00	0.00E+00
Exported energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	xx	xx	0.00E+00	0.00E+00	xx	0.00E+00	0.00E+00	0.00E+00

Table 14: Life Cycle Results, by information module (cont.)

Environmental Indicators	Unit	END OF LIFE stage: De-construction and Demolition C1	END OF LIFE stage: Transport C2	END OF LIFE stage: Waste Processing C3	END OF LIFE stage: Disposal C4	Total Life Cycle Results	SUPPL. INFO.: Benefits and loads beyond the system boundary D
Environmental Impacts							
Global warming potential	kg CO_2 eq.	1.83E+04	1.27E+04	xx	5.12E+03	3.04E+06	2.52E+05
Ozone depletion potential	kg CFC-11 eq.	8.01E-07	4.83E-07	xx	5.19E-04	8.93E-03	7.30E-04
Acidification potential	moles of H+ eq.	9.86E+02	4.22E+03	xx	1.69E+03	1.38E+06	7.12E+04
Eutrophication potential	kg N eq.	9.88E-01	4.22E+00	xx	7.59E+00	1.43E+03	2.32E+01
Photochemical smog potential	kg O_3 eq.	9.58E+01	2.07E+03	xx	8.85E+02	2.06E+05	1.16E+04
Abiotic resource depletion potential, elements	kg Sb eq.	xx	xx	xx	xx	xx	xx
Fossil fuel use	MJ	2.73E+05	1.73E+05	xx	4.49E+04	4.14E+07	2.77E+06
Human health criteria pollutants	kg PM10 eq.	2.44E+02	4.66E+00	xx	7.29E+00	1.24E+04	1.79E+02
Resource Use							
Renewable primary energy use, excluding feedstock	MJ	1.16E+02	2.53E+02	xx	2.52E+02	7.59E+06	2.34E+04
Renewable primary energy use, feedstock	MJ	0.00E+00	0.00E+00	xx	0.00E+00	2.14E+05	0.00E+00
Non-renewable primary energy use, excluding feedstock	MJ	2.73E+05	1.74E+05	xx	4.54E+04	1.05E+08	2.83E+06
Non-renewable primary energy use, feedstock	MJ	0.00E+00	0.00E+00	xx	0.00E+00	1.79E+06	0.00E+00
Secondary material use	kg	0.00E+00	0.00E+00	xx	0.00E+00	1.58E+05	-1.38E+06
Renewable secondary fuel use	MJ	xx	xx	xx	xx	xx	xx
Non-renewable secondary fuel use	MJ	xx	xx	xx	xx	xx	xx
Water use	m^3	0.00E+00	0.00E+00	xx	3.84E+00	1.61E+04	1.36E+03
Waste Categories							
Non hazardous waste to disposal	kg	1.86E+02	1.22E+02	xx	1.22E+06	1.54E+06	1.32E+05
Hazardous waste to disposal	kg	xx	xx	xx	xx	xx	xx
Radioactive waste	kg	xx	xx	xx	xx	xx	xx
Output Flows							
Components for reuse	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material for recycling	kg	0.00E+00	0.00E+00	1.31E+06	0.00E+00	1.38E+06	0.00E+00
Material for energy recovery	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

Figure 4: Information Module Contributions to Life Cycle Environmental Impacts

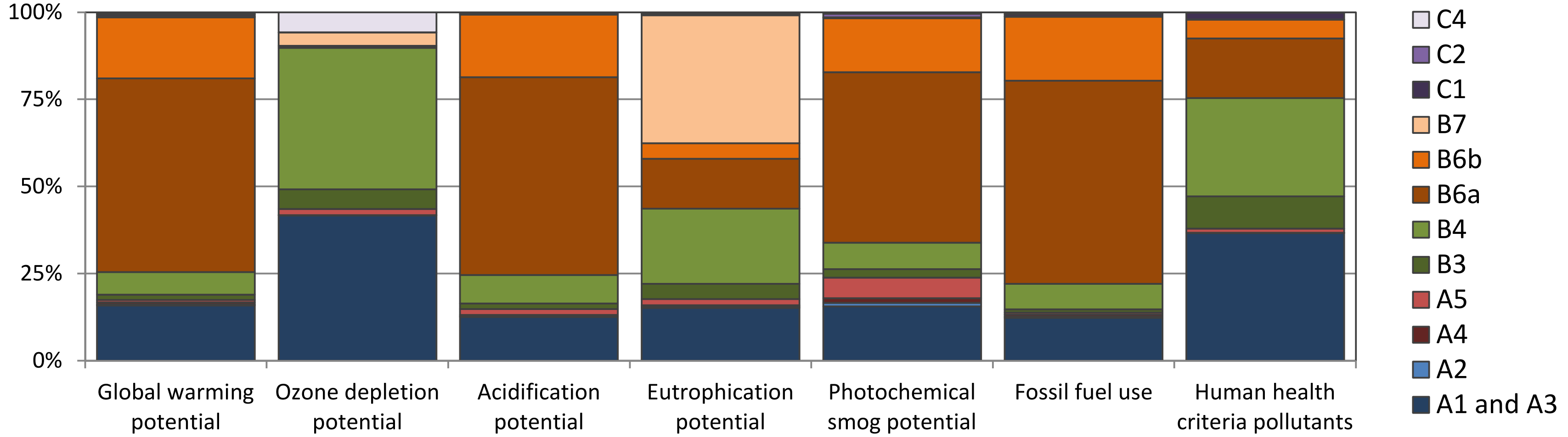
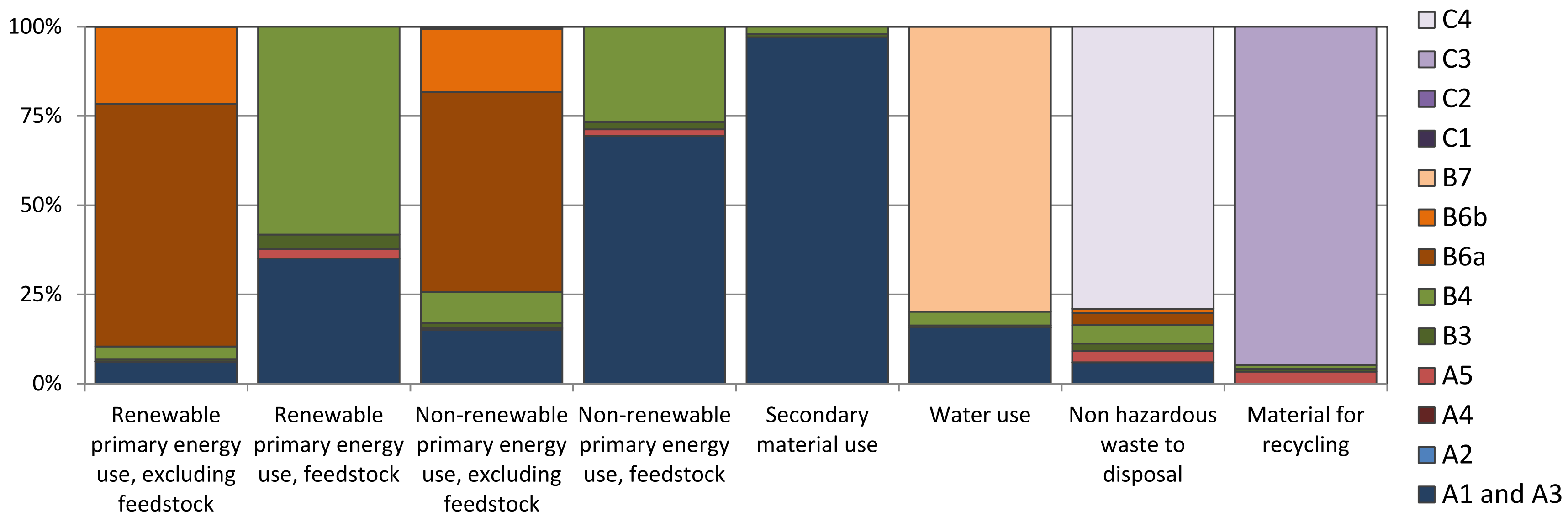


Figure 5: Information Module Contributions to Life Cycle Resource Use, Waste Categories, and Output Flows



7.2 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". The analysis presented in Table 15 shows the percent difference of the whole building results to 10% changes in certain model inputs (e.g. operating energy use, material takeoff quantities). This type of analysis serves to gauge the sensitivity of results to [1] the input quantities evaluated and [2] the influence of data chosen. The inputs analyzed include those shown to be significant contributors to the results (i.e. operating energy and water, 30 MPa concrete) and those whose LCI data was substituted with data for other materials (i.e. roof membrane and window frames). The sensitivity results indicate that operating energy use is significantly influenced by model inputs and the selected database. Changes to the Ontario grid mix in the future (e.g., natural gas substituting for coal used to generate electricity may markedly change the outcome of the assessment). All other inputs exhibit less sensitivity to a change in modeled quantities.

Table 15: Percent Difference of Building Results to 10% Changes in Model Inputs

Environmental Indicator	Operating Energy	Operating Water	Roof Membrane	Window Frame	30 MPa Concrete
Environmental Impacts					
Global warming potential	7.3%	0.0%	0.1%	0.0%	0.5%
Ozone depletion potential	0.1%	0.4%	1.2%	0.4%	1.5%
Acidification potential	7.5%	0.0%	0.1%	0.1%	0.3%
Eutrophication potential	1.9%	3.7%	1.7%	0.0%	0.1%
Photochemical smog potential	6.5%	0.0%	0.1%	0.0%	0.5%
Abiotic resource depletion potential, elements	xx	xx	xx	xx	xx
Fossil fuel use	7.7%	0.0%	0.1%	0.1%	0.3%
Human health criteria pollutants	2.3%	0.0%	0.0%	0.0%	0.7%
Resource Use					
Renewable primary energy use, excluding feedstock	8.9%	0.0%	0.0%	0.0%	0.0%
Renewable primary energy use, feedstock	0.0%	0.0%	0.0%	0.0%	0.0%
Non-renewable primary energy use, excluding feedstock	7.4%	0.0%	0.0%	0.0%	0.1%
Non-renewable primary energy use, feedstock	0.0%	0.0%	0.6%	0.5%	0.0%
Secondary material use	0.0%	0.0%	0.0%	0.0%	3.3%
Renewable secondary fuel use	xx	xx	xx	xx	xx
Non-renewable secondary fuel use	xx	xx	xx	xx	xx
Water use	0.0%	8.0%	0.1%	0.0%	0.1%
Waste Categories					
Non hazardous waste to disposal	0.4%	0.0%	0.0%	0.0%	3.8%
Hazardous waste to disposal	xx	xx	xx	xx	xx
Radioactive waste	xx	xx	xx	xx	xx
Output Flows					
Components for reuse	0.0%	0.0%	0.0%	0.0%	0.0%
Material for recycling	0.0%	0.0%	0.0%	0.0%	4.9%
Material for energy recovery	0.0%	0.0%	0.0%	0.0%	0.0%
Exported energy	0.0%	0.0%	0.0%	0.0%	0.0%