Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory

Daniel Tse

University of British Columbia

CIVL 498C

November 18, 2013

PROVISIO

This study has been completed by undergraduate students as part of their coursework at the University of British Columbia (UBC) and is also a contribution to a larger effort – the UBC LCA Project – which aims to support the development of the field of life cycle assessment (LCA).

The information and findings contained in this report have not been through a full critical review and should be considered preliminary.

If further information is required, please contact the course instructor Rob Sianchuk at rob.sianchuk@gmail.com

CIVL 498C

Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory

UBC LCA Database Project

Daniel Tse
[redacted]

November 18, 2013
Final Report

Table of Contents

Executive Summary

Project Context

This study is completed as the final report for the undergraduate civil engineering course CIVL 498C: Life Cycle Assessment. It is one of many building LCA studies completed as part of the larger UBC LCA Database Project. While significant development on this study was done by a previous author in 2009, this study represents the most complete compilation for product and construction process LCA results for the AERL building.

Methods

Significant previous work has already been completed to model and assess the environmental performance of AERL. The previous report author, Rob Sianchuk, orginated a quantity takeoff model, LCA building model, a spreadsheet documenting model input and assumptions, and a draft LCA report. These items were reviewed and improved upon to create this study.

Software has been a key component. Using On-Screen Takeoff v3.9.0.6, the original construction and architectural drawings were annotated to create quantity takeoffs for the entire building. Using the Athena Impact Estimator for buildings, these quantities were inputted and translated into environmental impacts. A pair of Excel spreadsheets has been utilized to document the input and assumptions between models.

This study presents environmental performance using the TRACI v2.1 impact assessment method. The Athena and US LCI databases are referenced by the IE. The study references a number of standards. Of note are ISO 14040, ISO 14044, and EN 15978.

Results

The functional unit is square meters of floor space (inclusive of slab-on-grade and suspended slabs). For AERL, this quantity is $5694\ m^2$. Environmental performance is evaluated by life cycle stage (product, construction process) and CIQS level 3 elemental format and normalized to the functional unit. Tables of values and figures of these results are given in Section *7.1 Life Cycle Results*.

Interpretation

The interpretation of results is made in the context of the environmental performance of all the other building LCA studies in the UBC LCA Database project. In other words, interpretation of AERL's environmental performance is referenced against this benchmark.

Comparison against the benchmark suggests two things. First, AERL creates less impacts per square meter than most buildings across all TRACI indicators. Second, the percent reduction in impact per square meter can be characterized by the global warming potential (units of kg CO2eq / m2). That is to say, one recommendation for operationalizing building LCA is to characterize performance in terms of a single indicator (in this case, global warming potential), with the understanding that this has the indirect effect of improving performance across all impacts.

Limitations

This study focuses on product and construction process stages; that is, this study does not consider use and end-of-life stages The building components considered in the model are limited to material, envelope, and barrier products. Paints/finishes and a host of building components (such as parapets) are not included in the model. In future years, the work of this study could be further developed to include additional life cycle stages as well increased scope of building materials and components.

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Description
AERL	Aquatic Ecosystems Research Laboratory
ASMI	Athena Sustainable Materials Institute
BCBC	British Columbia Building Code
BCFU	BC Fisheries Research Unit
BOM	Bill of materials
CEAB	Canadian Engineering Accreditation Board
CFC	Chlorofluorocarbon
CIQS	Canadian Institute of Quantity Surveyors
EPD	Environmental product declaration
FC	UBC Fisheries Centre
GHG	Greenhouse gas
HSS	Hollow structural steel (a type of steel column)
IE	Athena Impact Estimator for Buildings
IPCC	Intergovernmental Panel on Climate Change
IRES	The Institute for Resources, Environment, and Sustainability
LEED	Leadership in Energy and Environmental Design
LUCAS	LCIA method Used for a CAnadian-Specific context
NBCC	National Building Code of Canada
OST	On-Screen Takeoff
ReCiPe	RIVM and Radboud University, CML, and PRé Consultants
RJC	Read Jones Christofferson
SOG	Slab-on-grade
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
US EPA	United States Environmental Protection Agency
WMO	World Meteorological Organization
CH_4	Methane
CO_2	Carbon dioxide

1 General Information on the Assessment

This section introduces purpose and focus of this study.

1.1 Purpose of the Assessment

The purpose of this assessment is to quantify the environmental performance of the Aquatic Ecosystems Research Laboratory. This study is just one building assessed as part of a larger project, the UBC LCA Database Project. This larger project is one of the first of its kind: it represents one of the largest collections of institutional building LCA data. This study is an opportunity to evaluate AERL's LEED certification by another set of metrics, life cycle approaches. In addition, this study creates precedent for the design and construction of other buildings at UBC, since LCA is quickly becoming a requirement for projects at UBC.[1] Further, these studies act as learning tools and opportunities for teaching and applying life cycle methods in a practical and accessible context.

This assessment is intended to be used for benchmarking and subsequently, decision making. The aggregated average results of each building in the UBC LCA Database Project creates precedent for new buildings at UBC. This database could be utilized to compare the environmental performance of various building materials (concrete, steel, timber). It can also be used to track the relative changes in environmental performance of buildings over time.

The intended audience is diverse. Of note, policy makers, potentially those at UBC's Sustainability Office, would be interested in the results of this study. In addition, the intended audience includes engineering firms, contractors, financiers, developers, architects, building owners, and building occupants as these parties closely interact with buildings. Finally, the intended audience also includes any other bodies, such as government, or other interested parties, including the public.

Because this study is intended for benchmarking (and eventually policy making), it is not intended for comparative assertions.

Given the use of this study for benchmarking and policy making, level of detail should be detailed, but errors, omissions or inaccuracies do not render the results unusable. Instead, due the aggregative nature of the project, accurate or missing detail in one study will likely be highlighted and counterbalanced by well modelled results in another study. The use of CIQS level 3 elemental sorting reflects the idea that greatest opportunity for environmental performance of buildings is the onus of the design team. That is, CIQS is an elemental format is based around design elements (as opposed to formats such as MasterFormat, which prioritize costing and scheduling). The decision to exclude components such as landscaping, ceiling and acoustic finishes, lab/research equipment, mechanical/electrical systems, and furnishings reflects the product and construction process foci of this study.

---

[1] (UBC Building Operations, 2013)

1.2 Identification of Building

The Aquatic Ecosystems Research Laboratory, AERL, is described in Table 1.

Table 1: AERL At-a-Glance[2]

Aspect	Description
Storeys	4
Address	2202 Main Mall
Hours	Monday-Friday 08:00 – 17:30 Saturday/Sunday/Holidays CLOSED
Users	UBC Fisheries Centre (FC) The Institute for Resources, Environment and Sustainability (IRES) BC Fisheries Research Unit (BCFU)
Project Manager	Rob Brown
Architect	Patkau Architects
Structural Engineer	Read Jones Christofferson (RJC)
Construction	Bird Construction
Project Size	52,770 ft^2
Budget	$15,725,000
Completion	March 2006
Occupancy	March 2006
Sustainability Rating	LEED Gold (Certified) LEED-BC-NC 1.0; Gold certification; Project 10010[3]
Design Code	British Columbia Building Code 1998 (based on the National Building Code of Canada 1995)

The building, funded by the Federal Canada Foundation for Innovation and the Provincial BC Knowledge Development Fund,[4] has a single lecture hall (Room 12) with a capacity of 144 seats and approximately 330 open office desk spaces. [5] As described by the previous author, "The concept of combining these research units was to create an interdisciplinary research facility with a focus on the evaluation and management of fisheries in natural aquatic ecosystems"[6] In addition, the building is designed with a number of design features: [7]

- Passive air handling system
- Wet lab research area
- State of the art immersion lab
- Four storey atrium lobby
- Optimum light levels via strategic glazing (penthouse, size/placement of windows)

---

[2] (UBC Properties Trust, 2009)
[3] (Canadian Green Building Council, 2013)
[4] (Sianchuk, 2009)
[5] (Sianchuk, 2009)
[6] (Sianchuk, 2009)
[7] (Bird Construction Inc, 2013)

1.3 Other Assessment Information

Table 2 gives other assessment information for this study.

Table 2: Summary of Assessment Information

Assessment Information	Description
Client for assessment	Completed as coursework in a Civil Engineering technical elective course at the University of British Columbia
Name and qualification of the assessor	First author: Daniel Tse Second author: Rob Sianchuk, BScW, MASc
Impact assessment method	Athena Impact Estimator v4.2.0208 US EPA TRACI v2.1 (2007)
Point of assessment	7 years
Period of validity	5 years
Date of assessment	Completed in December 2013
Verifier	Student work – study not verified
Standards Referenced	EN 15978 ISO 14040 ISO 14044

2 General Information on the Object of Assessment

This section describes the functional unit, reference study period, and object of assessment scope.

2.1 Functional Equivalent

The basis for expressing the results of an LCA study is in terms of a function unit. According to ISO 14044, functional units are the “Quantified performance of a product system for use as a reference unit.”[8] It allows the results of the study to be normalized such that comparisons can be completed using a “common basis”.[9] The functional equivalent definition for AERL is given in Table 3.

Table 3: Functional Equivalent Definition

Aspect of Object of Assessment	Description
Building type	Institutional/Post-Secondary, Research[10]
Functional requirements	Research space – dry and wet labs, immersion lab Lecture seating for 144 occupants Office space
Technical requirements	LEED Gold (Certified) BCBC 1998, NBCC 1995
Pattern of use	144 lecture seats, 72 office spaces Significant lab research space Monday to Friday operating hours
Required service life	100 years[11]

For this study, the chosen functional unit is square metres of floor area (inclusive of all slab on grades and suspended slabs). Floor space can then be categorized in terms of use. Table 4 and Figure 1 summarize AERL’s functional areas in terms of square meters.

Table 4: AERL Functional Areas by Gross Floor Area

Functional Area Type	Gross Floor Area (m^2)
Auditorium/Lecture Hall	190
Computer Room	15
Elevator Shaft (inclusive of each floor)	21
First Aid	6
Hall/Atrium	817
Library	73
Mechanical/Electrical/Equipment	156
Offices	756
Research Lab	1809
Research Room	358
Stairs/Stairwells	229
Storage	33
Washroom	143

Figure 1: AERL Functional Areas by Percentage

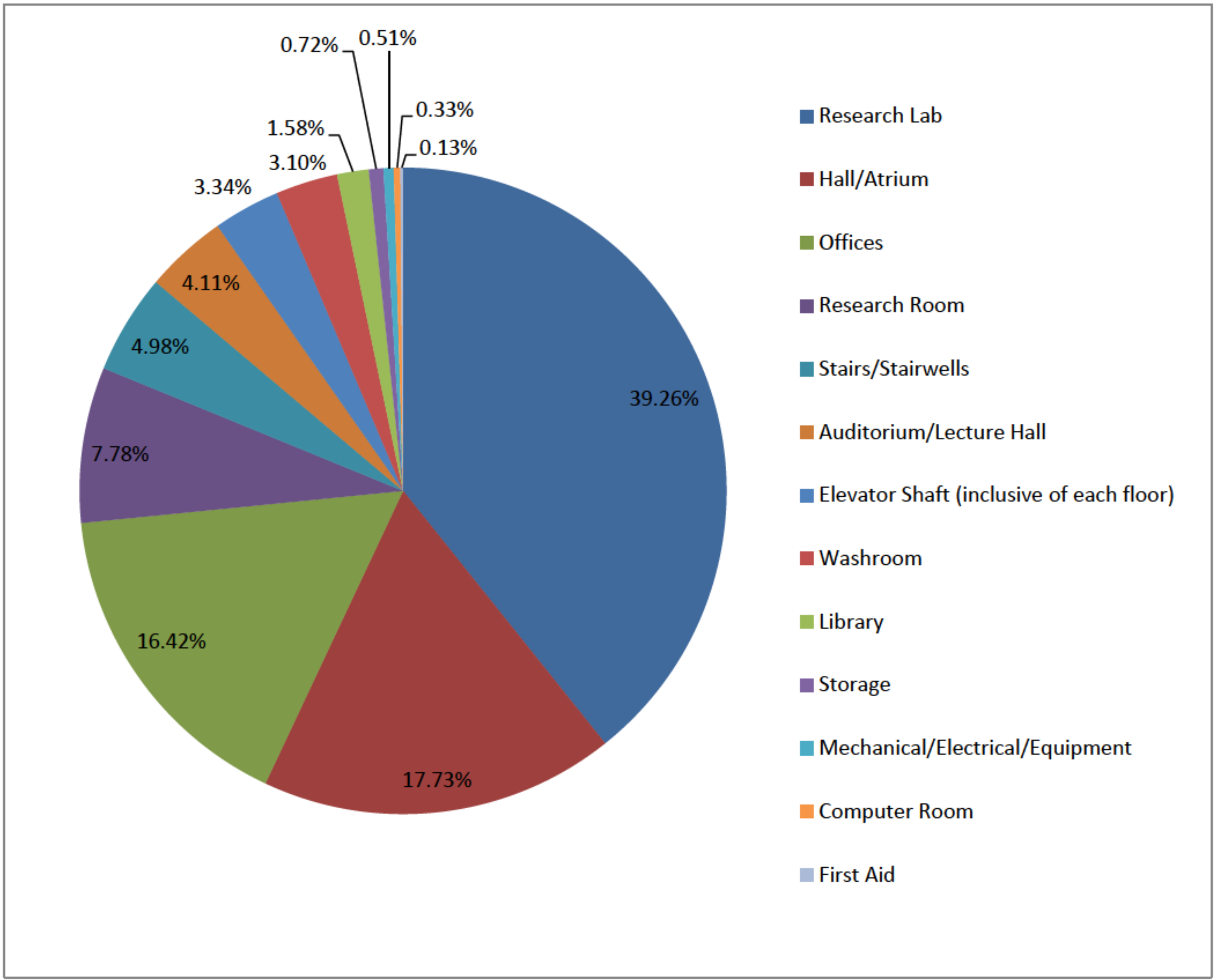
---

[8] (Standards Council of Canada, 2006)

[9] (Quantis US, 2009)

[10] (UBC Properties Trust, 2009)

[11] (UBC Building Operations, 2013)



2.2 Reference Study Period

The European Committee for Standardization (CEN) publishes collections of standards. *Sustainability of Construction Works* is one such collection. Of relevance to this LCA study is EN 15978: *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method.* [12]

According to EN 15978, building LCA standard by the European Committee for Standardization (CEN), the default value for the reference study period shall be the required service life of the building. For AERL, the required service life is 100 years; hence, the reference study period for this study is also 100 years.

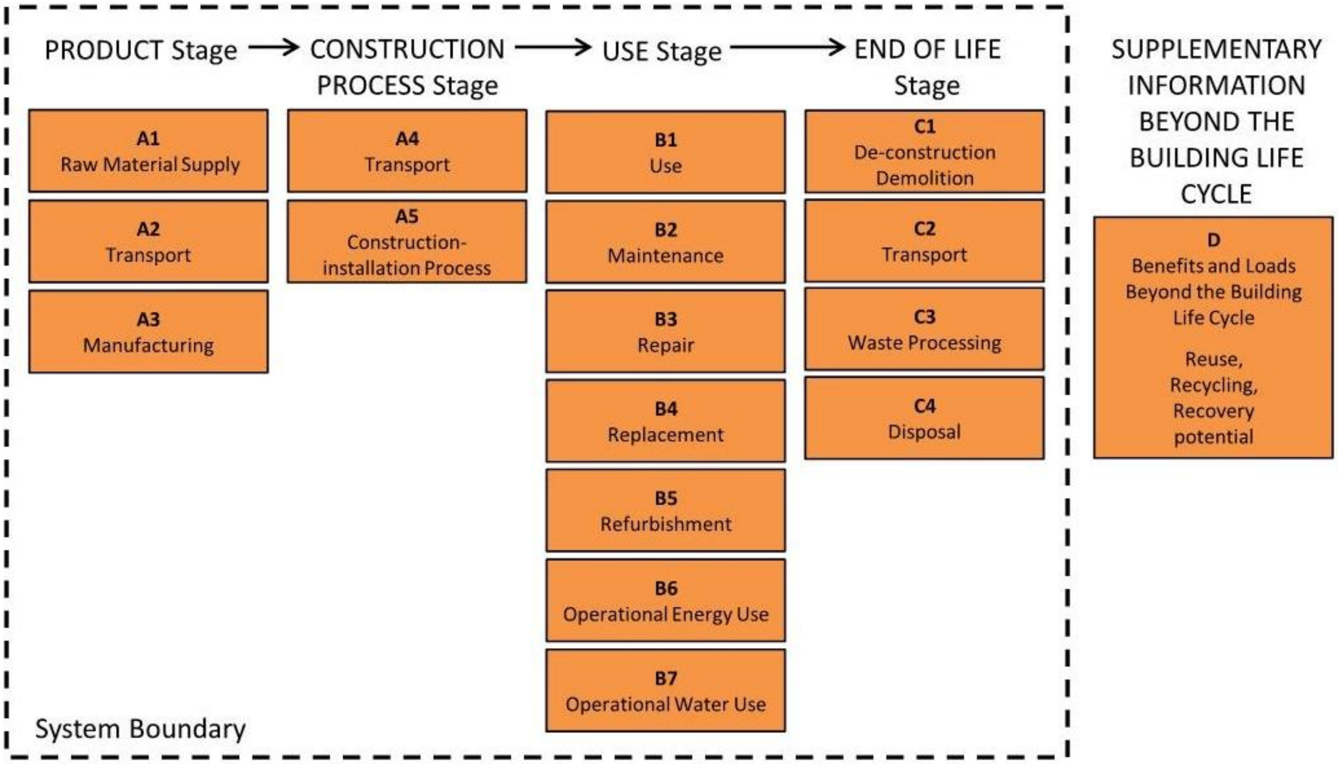
In addition to setting a standard for the reference study period, it describes the life cycle of building products and constructed works in two methods. The first method understands the study into four stages: product, construction process, use, and end-of-life. The second understands the study as a series of information modules: A1 through C4, and an additional Module "D".[13] This is shown graphically as Figure 2.

---

[12] (European Committee for Standardization, 2013)

[13] (Coldstream Consulting, 2011)

Figure 2: Whole-Building LCA Stages and Information Modules According to EN 15978[14]



For this study, Modules B, C, and D have been excluded. This is done for a number of reasons:

- This study emphasizes the product and construction processes stages (Module A)
- Modelling of use, end-of-life, and demolition stages (Modules B, C) is complex.

These studies can expanded to include additional modules in future years.

2.3 Object of Assessment Scope

According to EN 15978, the scope of a building LCA study should include the "foundations to the external works enclosed within the area of the building's site, over the reference study period."[15] However, the scope of this study deviates from the scope defined in EN 15978: it is limited to the structural components and envelope and barrier materials only. This reduction in scope is meant to focus and enhance the modelling and results the product and construction process stages. In addition, the reduced scope highlights the fact that this course is being offered through civil engineering.

For this study, a number of building systems have been excluded, such as: projects and overhangs, parapets, fittings and equipment, and finishes among other building systems. What is included in the study is summarized in two tables. Table 5 identifies aspects of AERL are included in this study by building system. Table 6 shows this same information but sorted to reflect CIQS level 3 elements. This sorting has been applied to reflect the Canadian context of this study. In addition, the fact that this sorting scheme is element emphasizes the potential use of LCA during the building design stages.

---

[14] (Coldstream Consulting, 2011)

[15] (Life Cycle Assessment Final Project Outline, 2013)

Table 5: AERL Building Definition by Building System[16]

Building System	Specific Characteristics of AERL
Structure	• Concrete and HSS columns supporting concrete suspended slabs
Floors	• Basement: concrete slab on grade • Ground, second, third, and fourth: suspended concrete slabs
Exterior walls	• Basement: cast-in-place concrete walls • Ground, second, third, and fourth: aluminum framed curtain walls; steel stud walls with modular brick cladding, extruded polystyrene, windows; cast-in-place concrete walls with modular brick cladding and extruded polystyrene • Penthouse: aluminum framed curtain walls
Interior walls	• Basement: gypsum on steel stud walls • Ground, second, third, and fourth: gypsum on steel stud walls, some acoustic batt insulation
Windows	• All windows and curtain walls low E tin glazed
Roof	• Main roof: suspended concrete slab with 2-ply SBS modified bitumen membrane roofing and polyisocyanurate insulation • Penthouse roof: steel deck with 2-ply SBS modified bitumen membrane roofing and polyisocyanurate insulation

Table 6: AERL Building Definition by CIQS Level 3 Element

CIVL 498C Level 3 Element		Description	Quantity (Amount)	Units
A11	Foundations	Strip and spread footings, various depths	1708	m^2
A21	Lowest Floor Construction	Slab on grade (125mm, 150mm, 200mm thick) - 150mm slab is exposed/outside walkway	1708	m^2
A22	Upper Floor Construction	Suspended slabs (200mm - ground, 2nd, 3rd, 4th), concrete/HSS steel columns (basement, ground, 2nd, 3rd), all staircases	3543	m^2
A23	Roof Construction	Suspended slab (200mm, roof), 4th floor columns (concrete, HSS steel), steel joist (penthouse)	1388	m^2
A31	Walls Below Grade	Cast-in-place concrete walls (150mm, 200mm, 400mm thick) of various wall assemblies	664	m^2
A32	Walls Above Grade	Cast-in-place concrete walls (300mm), concrete block walls (200mm thick) of various wall assemblies, curtain wall (steel spandrel and glazing), steel stud walls	3154	m^2
B11	Partitions	Cast-in-place concrete walls (200mm, 250mm, 400mm thick) of various wall assemblies, concrete block wall (200mm thick), curtain walls, steel stud partition walls of various assemblies	4894	m^2

---

[16] (Sianchuk, 2009)

3 Statement of Boundaries and Scenarios Used in the Assessment

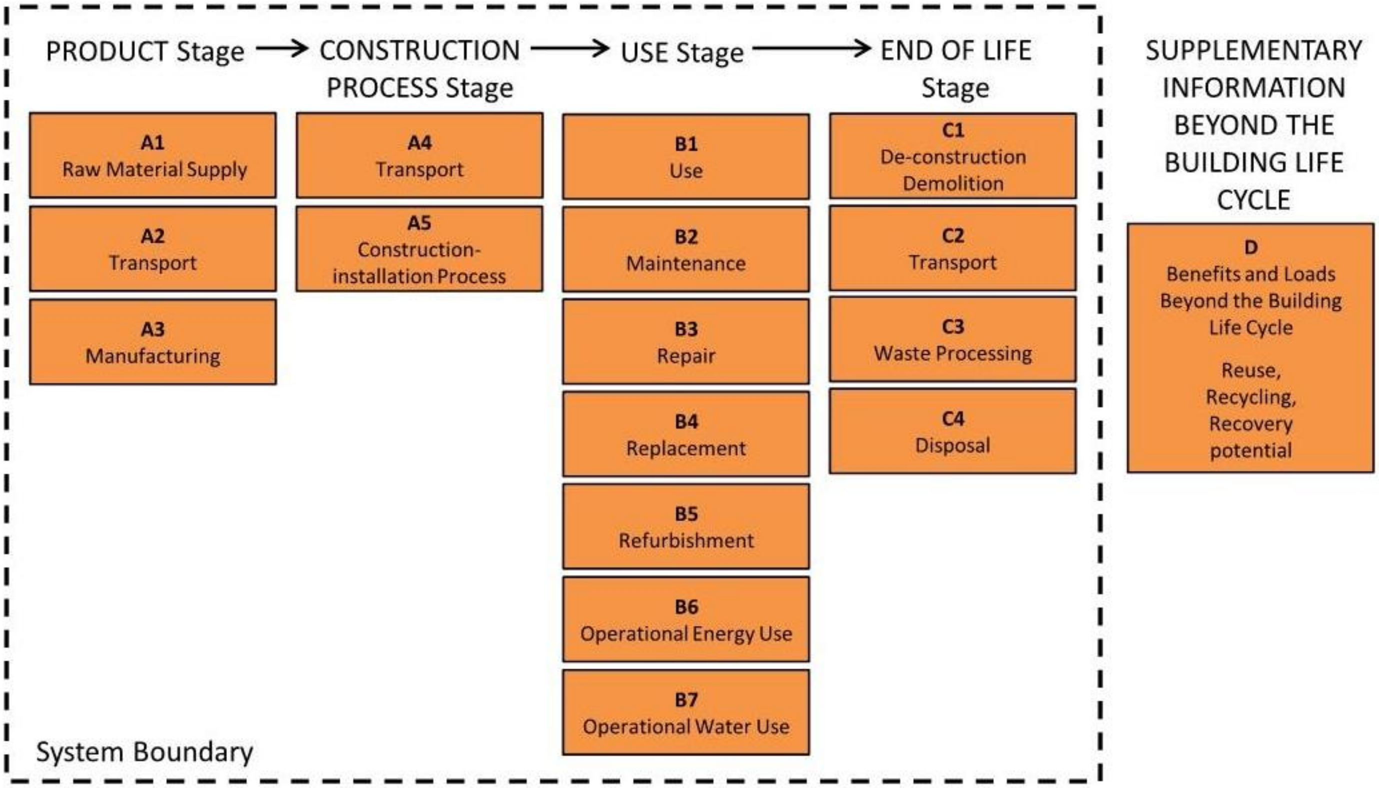
This section describes the system boundary detailed in standard EN 15978. A description of the production and construction process stages, the focus of this study, follows.

3.1 System Boundary

In utilizing EN 15978, the system boundary should include the four building life cycle stages (product, construction process, use, and end-of-life), as illustrated in Figure 3. While not shown in Figure 3, the system boundary also includes "all the upstream and downstream processes needed to establish and maintain the function(s) of the object of assessment, from the acquisition of raw materials to their disposal or to the point where materials exit the system boundary during the defined reference study period."[17]

However, this study focuses only on the product and construction process stages. The intent of this study is to determine the material and construction impacts and associated environmental impacts as mentioned in section *1.1 Purpose of the Assessment*.

Figure 3: Whole-Building LCA System Boundary According to EN 15978[18]



---

[17] (Life Cycle Assessment Final Project Outline, 2013)

[18] (Coldstream Consulting, 2011)

Table 7 and Table 8 give general descriptions downstream and upstream processes that support the information modules of the produce and construction process stages, respectively. These sections are described further in sections *3.2 Product Stage* and *3.3 Construction Process Stage*.

Table 7: Product Stage Upstream and Downstream Processes for a 100 Year Reference Study Period

Information Module		Downstream Processes	Upstream Processes
A1	Raw Material Supply		
A2	Transport		
A3	Manufacturing		

Table 8: Construction Process Stage Upstream and Downstream Processes for a 100 Year Reference Study Period

Information Module		Downstream Processes	Upstream Processes
A4	Transport		
A5	Construction-Installation Process		

3.2 Product Stage

The product stage includes the process between material extraction and material production. Because standard EN 15978 is not publically accessible and no suitable alternate sources were located, this section contains the author's best estimates of the process information at the product stage.

The following are considered in the manufacturing module:

- The energy requirements during manufacturing could be characterized the plant energy operating requirements. However, the energy requirements also need to reflect the upstream energy production impacts. For example, if a manufacturing plant is powered by coal-generated electricity, the emissions to land, water, and air need to account for the emissions created during the manufacturing process in addition to those generated during the burning of the coal.
- Impacts for packaging should be considered in a similar manner.

The following are considered in the transportation module:

- Transportation could include the energy requirements between the extraction and refinement point and from one refinement point to another until the final product
- Energy and emissions are also assumed to be generated during the transportation of manufacturing wastes.

3.3 Construction Process Stage

The construction stage includes the process between products leaving the factory gates until the practical completion of construction works.

The following are considered in the transportation module:[19]

- Transportation accounts for energy required to transport material from a factory to a regional distribution centre, and then onwards to the construction site. Distances are based on regional surveys.
- It is assumed that a similar procedure is used to quantify the energy requirements for waste disposal.

The following are considered in the construction-installation module:[20]

- Energy requirements are considered in the construction of a given building assembly. For example, operating a concrete pump would require a different amount of energy consumption than operating a pile driving rig. Both, however, would have different emissions to land, air and water.
- Weather and temperature conditions affect the energy and material requirements. For example, additional energy and material would be required to properly cure concrete in cold temperatures.
- For mid- and high-rise structures, energy requirements are considered when hoisting material to the required elevation. The same can be assumed for deep excavations.

---

[19] (Athena Sustainable Materials Institute, 2013)

[20] (Athena Sustainable Materials Institute, 2013)

4 Environmental Data

This section discusses data sources, data adjustments and substitutions, and data quality.

4.1 Data Sources

The IE combines two main sources of data:

1) Athena LCI Database for material process data
2) US LCI Database for energy combustion and pre-combustion processes for electricity generation and transportation

The use of this database information is integrally built into the function of the program; that is, they "are not appropriately viewed as standalone files because they are designed to work only in the context of the data integration undertaken by the Impact Estimator."[21]

4.1.1 Athena LCI Database

The Athena Institute was started in 1989 as Forintek Canada Corp. Originally a wood products research institute, Forintek received national funding to research the environmental footprints of other building materials such as steel and concrete. By the mid-1990s, this work became known as the "Athena Project". In 1996, the Athena Institute became a separate entity from Forintek.[22] Athena has been conducting life cycle research since 1989. Today, the institute studies energy use, transportation, construction and demolition, maintenance, repair and replacement effects, and demolition and disposal environmental impacts in addition to the original material impacts.[23]

This database includes a wide range of structural and envelope materials.[24] For structural materials, it includes various types of concrete, steel, wood, and wood composite materials. For envelope details, this database has information on cladding, insulation and barrier products, paint, gypsum board, roofing products and windows.

The ASMI ultimately manages this database. They utilize a "membership-based non-profit research collaborative"[25] model, which means data is not publically available. They grow and maintain the database in two ways. They secure research contracts from industry and produce industry averages on "commodity products such as concrete, lumber, gypsum, etc."[26] For other data, such as demolition and end-of-life processes, Athena membership fees and research grants are utilized.[27]

4.1.2 US LCI Database

The US LCI database was conceived on May 1, 2001. The project "gained national prominence at a meeting of interests hosted by the Ford Motor Company" Since then, representatives from manufacturing, government, non-government organizations, and LCA experts have come together to form an advisory committee for the database.[28] The Athena Institute made a major contribution to the database in 2002. [29]

---

[21] (Athena Sustainable Materials Institute, 2013)
[22] (Athena Sustainable Materials Institute, 2013)
[23] (Athena Sustainable Materials Institute, 2013)
[24] (Athena Sustainable Materials Institute, 2013)
[25] (Athena Sustainable Materials Institute, 2013)
[26] (Athena Sustainable Materials Institute, 2013)
[27] (Athena Sustainable Materials Institute, 2013)
[28] (National Renewable Energy Laboratory, 2010)
[29] (Athena Sustainable Materials Institute, 2013)

The materials included in this database are extensive. However, the IE uses only energy data from this database. To account for regional difference, electricity generation profiles are chosen based on provide, regional, or continental criteria. This database is publically accessbile.

The US LCI database is managed by the National Renewable Energy Lab.[30] There are currently two lead researchers:[31] Michael Deru, PhD and Alberta Carpenter, PhD. The Athena Institute uses this database for energy consumption impacts, they have been "major proponents of, and contributors to, the US LCI Database."[32]

4.2 Data Adjustments and Substitutions

Although the IE is designed to specificity of a wide range of construction products and materials, there are still instances where the program does not have information for a given product of material used in the actual building construction. In such cases, it would be prudent for the modeller to find other suitable data such that the environmental impacts of these products can be better quantified.

Section *6.4.3 Material Types and Properties* discusses these sort of material improvements further. Example material type and properties are presented, and a general methodology for quantifying their impacts is presented.

4.3 Data Quality

Data quality describes the level with which it satisfies stated requirements. Where the data does not meet these requirements, it is described as uncertain. Table 9 describes five types of data uncertainty covered in this study while Table 10 gives study specific examples at the inventory analysis stage.

Table 9: Description of Types of Data Uncertainty by LCA Stage[33]

Uncertainty	Description
Data	Data uncertainty is associated with the actual collected numbers; uncertainty during data collection must be propagated throughout the analysis
Model	Model uncertainty is associated with the analysis method of collected data. In particular, this is qualified as whether a model is linear or non-linear. For example, model uncertainty asks whether a given amount of input will result in less output (non-linear), the same amount of output (linear), or more output (non-linear). Model uncertainty also includes the chosen impact assessment method. Using North American metrics (TRACI, LUCAS) provides different outcomes than using European metrics (ReCiPe), for example.
Temporal	Temporal uncertainty is associated with change of data for a given product over time; it considers improving technologies over time as well as environmental mechanisms or chemical reactions which require significant time to become visible and quantifiable (ie. acquifer damage).
Spatial	Spatial uncertainty is associated with regional differences in data
Variability between Sources	This type of uncertainty is associated with differences in data given that temporal and spatial uncertainty is minimal. That is, this is the remaining uncertainty in the case that, for example, two factories in the same region operating at the same time. It accounts for the differences between factories, such as the production technologies employed. In addition, it includes differences in human exposure patterns. For example, children and infants are more susceptible to endocrine disrupting compounds than adults.

---

[30] (Athena Sustainable Materials Institute, 2013)

[31] (National Renewable Energy Laboratory, 2010)

[32] (Athena Sustainable Materials Institute, 2013)

[33] (Week 8 Notes, October 23, 2013)

Table 10: Study-Specific Examples of Uncertainty at the Inventory Analysis Stage[34]

Uncertainty	Inventory Analysis	Study Specific Example
Data	Data collection and allocation procedures; inaccurate or missing data	Uncertainty in the completeness of the quantity takeoffs completed in OST
Model	Linear or non-linear modelling	–
Temporal	Differences in yearly factory emissions; data vintage	For the overall UBC LCA Database Project, a number of buildings contain banned substances such as asbestos. Uncertainty results because studies are not, and likely will not be, conducted on such materials.
Spatial	Regional differences between factories	Uncertainty in the use of cementitious materials regionally: Vancouver uses flyash, but Ontario uses slag. Both are cementitious materials, but they are by products of dissimilar industrial process. However, the IE only considers the use of flyash in concrete.
Variability between Sources	Differences between factories; differences in production technologies for the same product	There are a number of concrete suppliers in Vancouver which are located at different distances from a given building site. The source of their aggregates, and the efficiency and configuration of their batch plants could differ.

---

[34] (Week 8 Notes, October 23, 2013)

5 List of Indicators Used for Assessment and Expression of Results

The indicators used for this study are based on the TRACI (2007, v2.1) midpoint assessment method. [35] While the IE uses the TRACI impact assessment method, the program excludes Human Health Cancer, Noncancer, and Ecotoxicity indicators. In lieu, Fossil Fuel Consumption, an indicator from the LCI database, is substituted. One reason for this exchange is the fact that significant quantities of energy go into producing many construction materials; in addition, energy requirements are non-negligible for on-site construction practices. Without this indicator, the assessment is not as valid.

To aggregate the environmental impacts of a host of emissions, characterization factors are used to determine the equivalency of one emission in terms of a reference emission. The IE has characterization factors built into the program.

Table 11 summarizes the impact categories used in this study. A detailed description of the impact categories, including a general description of the cause/effect chain modelled, is given in Table 12.

Table 11: Assessment Indicators and Possible Endpoint Impacts

Assessment Indicator	Category Indicator	Characterized By	Possible Endpoint Impacts
Acidification Potential	$kg\ SO_2\ eq$	US EPA	Habitat loss, biodiversity loss, ecosystem disruption, agricultural effects, infrastructure effects, flora and fauna mortality
Eutrophication	$kg\ N\ eq$	US EPA	Habitat loss, biodiversity loss, ecosystem disruption, hypoxic aquatic environments
Fossil Fuel Consumption	MJ	Athena Sustainable Materials Institute	Global warming potential, resource depletion, agricultural effects
Global Warming Potential	$kg\ CO_2\ eq$	Intergovernmental Panel on Climate Change (IPCC)	Water resource effects, human health, agricultural effects, forest effects, species damage, coastal area damage[36]
Human Health Respiratory Effects Potential	$kg\ PM_{2.5}\ eq$	US EPA	Human health (loss of life, productivity, enjoyment),
Ozone Depletion	$kg\ CFC\text{-}11\ eq$	World Meteorological Organization (WMO)	Agricultural effects, reproduction effects, material degradation effects
Photochemical Smog Potential	$kg\ O_3\ eq$	US EPA	Human health (loss of life, productivity, enjoyment), cancer potential

---

[35] (United States Environmental Protection Agency, 2012)

[36] (Week 6 Notes, October 9, 2013)

Table 12: Assessment Indicators and Cause/Effect Chains

Assessment Indicator	Cause/Effect Chain
Acidification Potential	A variety of gaseous compounds hold the potential for being acidic in the environment. Wet deposition occurs when these compounds come into contact with water. Hence, during precipitation events, these compounds acidify lakes and streams. By contrast, if these gases remain dry, they will eventually accumulate on the ground as particulates, at which point they will acidify if hydrated.
Eutrophication	The release of excess nutrients (in the form of nitrogen or phosphorus, often from fertilizers) into water bodies promotes the excess growth of phytoplankton. As the algae bloom dies, the dissolved oxygen content in the water is depleted. At the same time, the algae bloom releases toxic substances such as cyanobacteria. Hence, aquatic life is damaged and water is no longer fit for consumption.
Fossil Fuel Consumption	This impact category includes "all energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources."[37]
Global Warming Potential	An excess of greenhouse gas (GHG) emissions (such as CO_2 and CH_4 for example) absorbed infrared radiation from the sun, which heats the atmosphere; in turn, this affects the climate, precipitation patterns, and sea levels.[38]
Human Health Respiratory Effects Potential	Air emissions often contain both gaseous and particular matter. When particulate matter is inhaled, it is deposited in the lungs. Inhalation of these particulates affects human health and mortality, especially when they contain harmful compounds.[39]
Ozone Depletion	As chlorofluorocarbons (CFC) disperse into the atmosphere, UV rays from the sun "knockout" or ionize a chlorine atom from the parent molecule; at this point, the highly reactive chlorine free radical (a chlorine atom without a complete set of electrons) reacts with (stratospheric) ozone to produce oxygen and other compounds.
Photochemical Smog Potential	Volatile organic compounds (benzenes, etc) as well as nitrous oxides react in the troposphere in the presence of sunlight to form ozone. Exposure to ozone is harmful for humans and plants. [40]

---

[37] (Week 6 Notes, October 9, 2013)
[38] (Week 6 Notes, October 9, 2013)
[39] (Week 6 Notes, October 9, 2013)
[40] (Week 6 Notes, October 9, 2013)

6 Model Development

This section describes the model development in terms of quantity takeoffs, modeling of assembly groups, model review and sorting, model improvements, impact assessment and net present value.

6.1 Quantity Takeoffs

In order to determine the impacts of materials used in the construction of AERL, an accurate estimation of material quantities is required. Quantity takeoffs is the concept of calculating the required quantities of a given construction material in a building. For this study, an estimating program called On-Screen Takeoff (OST) (v3.9.0.6) is used.

6.1.1 Construction and Architectural Drawings

The record drawings drafted in part by the structural engineering firm Read Jones Christofferson (JRC) are the main source of quantity information. From these drawings, it is possible to determine, for example, precise volumes of concrete for footings, columns, slabs, and walls among other cast-in-place concrete components. With sufficient effort and expertise, it is possible to determine with great precision the quantities of all structural and building elements. In some instances, quantities are also derived from the architectural drawings as well.

By contrast, the architectural drawings are used to identify the placement of a specific type of wall, partition, floor slab, ceiling finish, or acoustic finish among other assemblies. They also provide detail for placement of equipment (both on the floor and on the ceilings). For this study, these drawings are used primarily to reference the location of specific wall and partition assemblies.

6.1.2 Architectural Construction Assemblies

This document by the architectural firm describes the materials in a specific assembly. For this study, it is used to determine the envelope and barrier characteristics for the roof, exterior wall, floor, and interior partition assemblies. However, it also contains details for parapet, acoustic wall finish, ceiling/acoustic ceiling/soffit assemblies as well, all of which are not included in the scope of this study.

6.1.3 On-Screen Takeoff

In this study, On-Screen Takeoff is used to determine material quantities that are not easily determine by reading the construction drawing. OST functions by creating links to existing drawing sets at the proper scale. Users generate specific types of condition to annotate a given drawing. In order to maintain structure, conditions can be organized by condition type, and further organized into folders. Once the takeoffs are complete, they can be exported into other formats.

OST contains three conditions: area, linear, and count. Area conditions are used, for example, to determine the area of a spread footing or the area of a window. Walls and strip footings are modelled well as linear conditions. Finally, the number of columns, windows, or offices can be modelled with the count condition. However, it is often the case that a combination of conditions is required to estimate the total quantity of a given assembly. For example, the total surface area of windows can be determined by a combination of count and area conditions.

Still, some quantities cannot be fully estimated using just OST. For HSS columns, OST can determine the count each type of column; at best, the program will give the total linear length of each type of column; however, to obtain an equivalent volume of steel, cross-sectional areas must be referenced from texts such as the Handbook of Steel Construction (10E).

6.2 Modelling of Assembly Groups

The assembly groups noted here are chosen to reflect the way the IE operates. A comprehensive explanation of the modelling process has already been written[41] by the previous author (Rob Sianchuk). As a result, the content provided in this section is largely a paraphrase of the previous work. In some instances, where improvements are not made to the existing text, an excerpt is provided .

6.2.1 Foundations

There are two types of assemblies within the foundations assembly group: concrete slab-on-grade (SOG) and concrete footings. Concrete stairs are modelled as concrete footings.

SOG is measured as an area condition. Because the IE takes length and width inputs with fixed thicknesses (100mm or 200mm), it is sometimes necessary to scale the length and width dimensions to compensate for a thickness other than 100mm or 200mm. For AERL, there are three SOG thicknesses: 125mm, 150mm, and 200mm. The extents of each SOG is given on structural drawing 316-07-003.

There are three types of footings in AERL: spread and strip footings. Spread footings have variable length, width, and thickness. They are measured using area conditions. Strip footings, however, have constant width and depths. Hence, they are measured using linear conditions. The previous modeller (Rob Sianchuk) used a previous version of the IE (version not stated) where footing thicknesses were “limited to be between 7.5” and 19.7” thick”. While the current version of the IE (v. 4.2.0208) has lifted the thickness restriction on footings, the inputs have not been changed since the quantities remain sound. Structural drawing 316-07-003 contains a footing schedule and details the location of each footing.

The concrete stairs on either side of the building are modelled as footings. A measured average thickness (structural drawing 316-07-002), width (structural drawing 316-07-010), and linear condition (architectural drawing 316-06-014) for the length are used as inputs to the IE.

6.2.2 Walls

The wall assemblies had the largest amount of variation of all the building assembly groups. With reference to the architectural construction assemblies, walls can be grouped as exterior or partition (interior) walls. According to this document, there are a total of 17 different wall assemblies. OST was used with linear counts to determine the length of a given wall type. To account for glazing, count and area conditions were used: the area of a single window is multiplied by the number of windows. A similar procedure is used to account for doors. Additional assumptions are contained in Annex *D – Impact Estimator Inputs and Assumptions*.

6.2.3 Mixed Columns and Beams

The methodology to model mixed columns and beams in the IE is described well by the previous author. As was previously written:

> The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs: number of beams, number of columns, floor to floor height, bay size, supported span and live load. This being the case, in OnScreen, since no beams were present in the AERL building, concrete columns were accounted for on each floor using a count condition, while each floor’s area was measured using an area condition. The number of beams supporting each floor is assigned an average bay and span size in order to cover the measured area, which are seen in the Input Assumption Document. Since the live loading was not located within the provided information, a live load of 75psf on all four floors and the basement level were assumed. The hollow structural steel (HSS) columns in

---

[41] (Sianchuk, 2009)

the AERL building were modeled in the Extra Basic Materials, where their associated assumptions and calculations are also documented.

However, the information provided for this report contains live load demands. Table 13 gives the design live loads, as listed in structural drawing 316-07-001. With reference to Table 13, any improvements are discussed further in Section *6.4 Model Improvements*.

Table 13: Design Live Loads (Structural Drawing 316-07-001)

Design Live Load	$kN/m^2 = kPa$	psf
Roof (Ground Snow and Rain Load)	1.9 + 0.3	45
Office Floors	3.1	65
Laboratory	3.6	75
Mechanical Room	3.6	75
Lobby Level Interior	4.8	100
Stairs and Corridors	4.8	100

6.2.4 Floors

Using OST, floor area is measured as an area condition. The IE takes floor width and span, as well as concrete strength, percent flyash, and live load as modelling inputs. To be clear, thickness is not a required input. Information on the flyash content of the concrete was not provided in the structural drawing general notes (316-07-001, 316-07-002)—hence an "average" flyash content is assumed. While the floors support design live loads of $3.1\ kPa$, $3.6\ kPa$ and $4.8\ kPa$, the majority of the area is laboratory and office space. Hence, a live load of $3.6\ kN/m^2$ is inputted into the model. The concrete strength is assumed to be 30 MPa even though structural drawing 316-07-001 indicates a design compressive strength of 25 MPa (at 28 days).

6.2.5 Roof

The roof for AERL comprises of a suspended concrete slab in conjunction with a steel joist for the penthouse. Both were modelled as area conditions in OST. For the concrete slab, the live load was modelled as $2.4\ kPa$ rather than a combined design live load of $2.1\ kPa$. Again the concrete strength is modelled as $30\ MPa$ rather than $25\ MPa$ (at 28 days). The steel joist roof was modelled as a steel joist assembly.

6.2.6 Extra Basic Materials

HSS steel columns are modelled as extra basic materials. Count conditions were used to determine the quantity of each type of column. Linear densities are obtained from the Handbook of Steel Construction (10th Edition) to determine the total mass of steel.

6.3 Model Review and Sorting

Model review and sorting comprises of re-organizing the original OST, IE, and excel files according to CIQS level 3 elements. The bill of materials and summary measures from the original model are given here for reference.

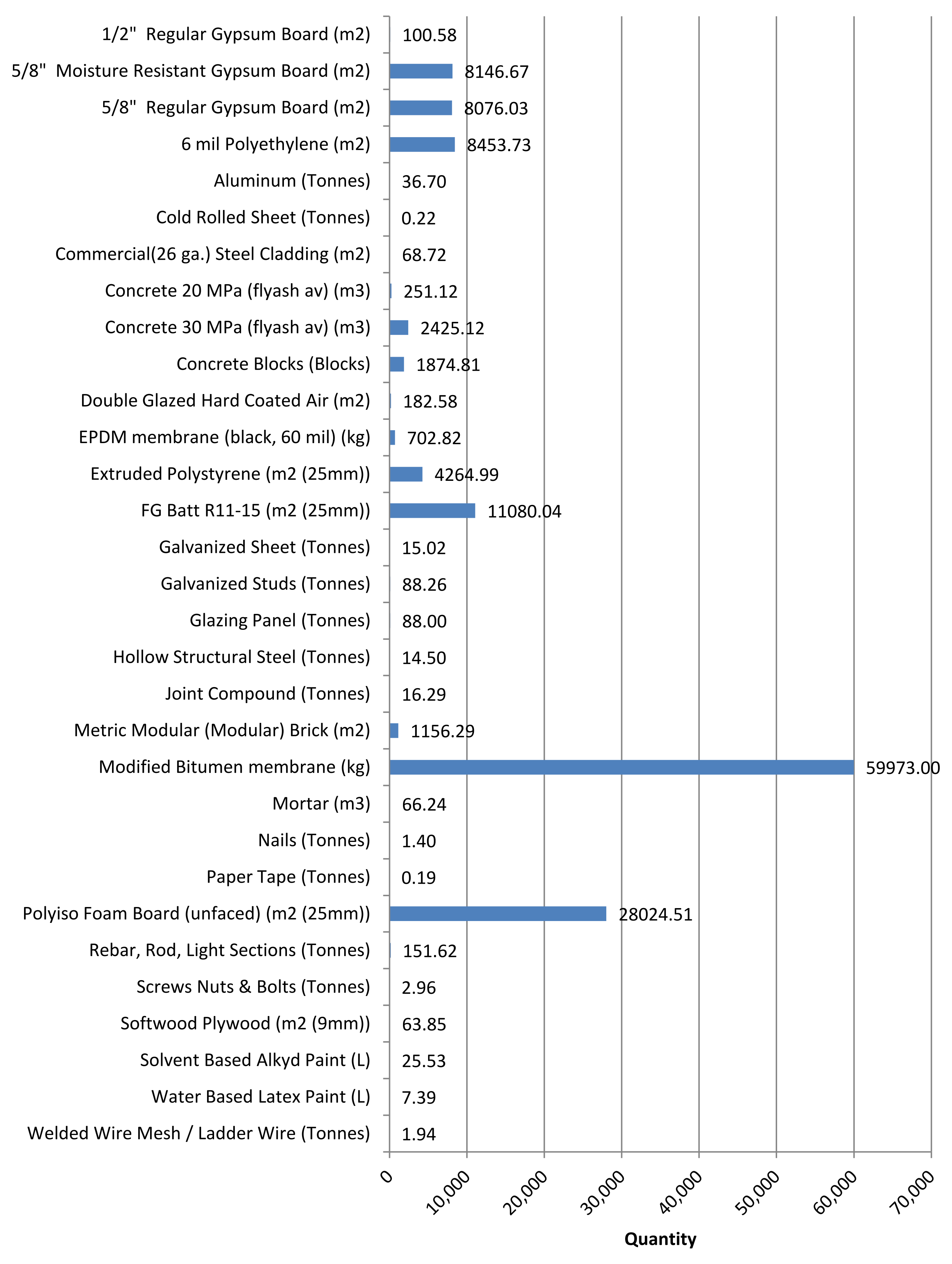
6.3.1 Original Bill of Materials

The bill of materials generated for the IE model completed by the previous author is summarized in Table 14 and Figure 4. Of note is the fact that the three largest quantities are all insulation products: modified bitumen membrane (59973.00 kg), polyiso foam board (unfaced) (28024.51 m^2 (25mm)), and FG Batt R11-15 (11080.04 m^2 (25mm)).

Table 14: Original Whole-Building Bill of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	100.58	m^2
5/8" Moisture Resistant Gypsum Board	8146.67	m^2
5/8" Regular Gypsum Board	8076.03	m^2
6 mil Polyethylene	8453.73	m^2
Aluminum	36.70	$Tonnes$
Cold Rolled Sheet	0.22	$Tonnes$
Commercial(26 ga.) Steel Cladding	68.72	m^2
Concrete 20 MPa (flyash av)	251.12	m^3
Concrete 30 MPa (flyash av)	2425.12	m^3
Concrete Blocks	1874.81	$Blocks$
Double Glazed Hard Coated Air	182.58	m^2
EPDM membrane (black, 60 mil)	702.82	kg
Extruded Polystyrene	4264.99	$m^2\ (25mm)$
FG Batt R11-15	11080.04	$m^2\ (25mm)$
Galvanized Sheet	15.02	$Tonnes$
Galvanized Studs	88.26	$Tonnes$
Glazing Panel	88.00	$Tonnes$
Hollow Structural Steel	14.50	$Tonnes$
Joint Compound	16.29	$Tonnes$
Metric Modular (Modular) Brick	1156.29	m^2
Modified Bitumen membrane	59973.00	kg
Mortar	66.24	m^3
Nails	1.40	$Tonnes$
Paper Tape	0.19	$Tonnes$
Polyiso Foam Board (unfaced)	28024.51	$m^2\ (25mm)$
Rebar, Rod, Light Sections	151.62	$Tonnes$
Screws Nuts & Bolts	2.96	$Tonnes$
Softwood Plywood	63.85	$m^2\ (9mm)$
Solvent Based Alkyd Paint	25.53	L
Water Based Latex Paint	7.39	L
Welded Wire Mesh / Ladder Wire	1.94	$Tonnes$

Figure 4: Bar Graph of Original Whole-Building Bill of Materials



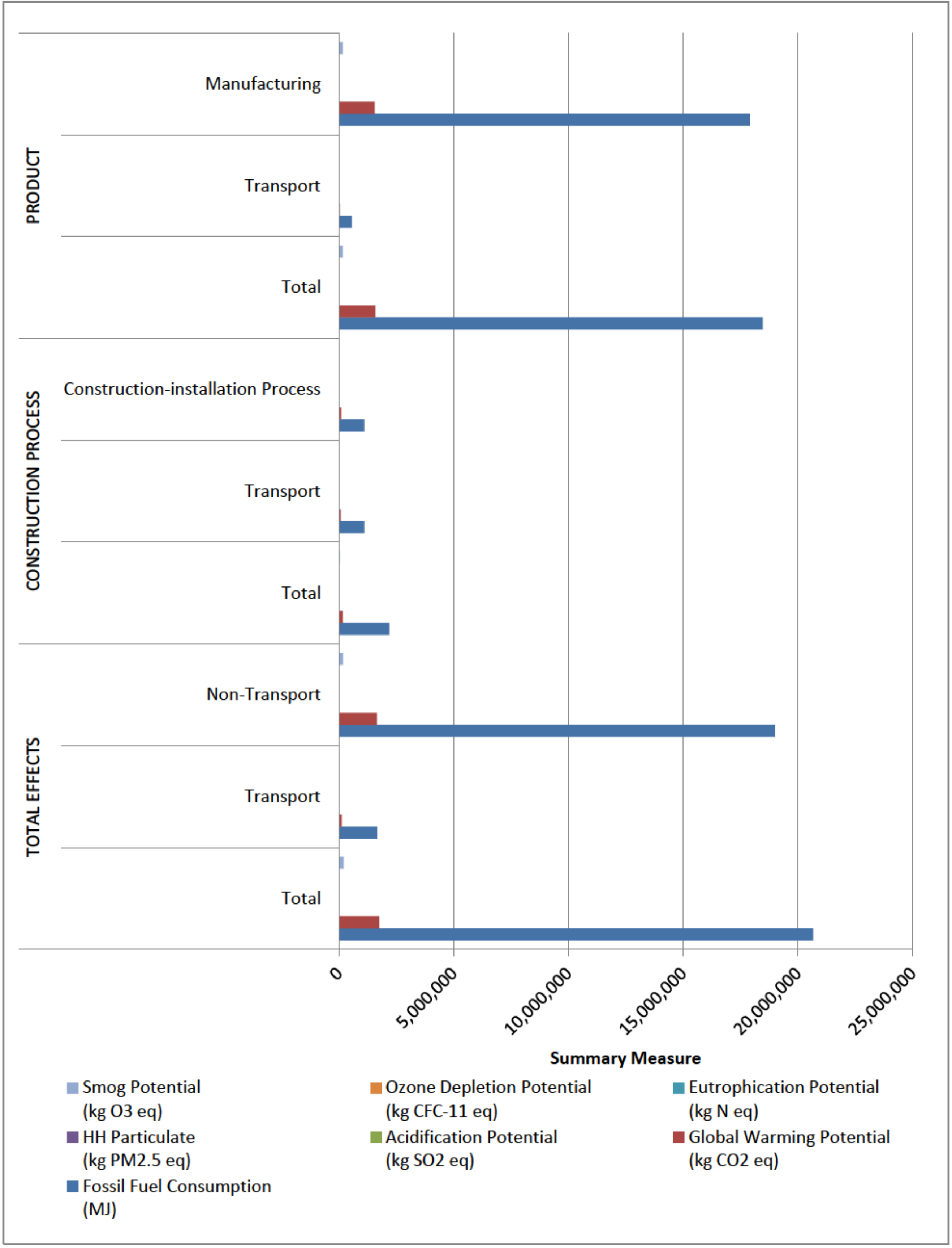
6.3.2 Original Summary Measure Report

The summary measure report generated by the IE model completed by the previous author is summarized in Table 14 and Figure 5. Fossil fuel consumption is the largest impact across all categories. Global warming potential is the second largest impact. Because this study is limited to the material (product) and construction impacts, the use and end-of-life phase summary measures are omitted.

Table 15: Original Whole-Building Summary Measure Report

Summary Measures		Fossil Fuel Consumption (MJ)	Global Warming Potential (kg CO2 eq)	Acidification Potential (kg SO2 eq)	HH Particulate (kg PM2.5 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O3 eq)
PRODUCT	Manufacturing	1.79E+07	1.56E+06	1.17E+04	6 84E+03	6.61E+02	8.78E-03	1.61E+05
	Transport	5.60E+05	3.23E+04	2.04E+02	5.70E+00	1.42E+01	1.32E-06	7.22E+03
	Total	1.85E+07	1.59E+06	1.19E+04	6 84E+03	6.75E+02	8.79E-03	1.68E+05
CONSTRUCTION PROCESS	Construction-installation Process	1.10E+06	9.02E+04	6.40E+02	1 20E+02	3.55E+01	3.71E-04	1.68E+04
	Transport	1.10E+06	7.65E+04	3.89E+02	1.17E+01	2.78E+01	3.06E-06	1.38E+04
	Total	2.20E+06	1.67E+05	1.03E+03	1 32E+02	6.33E+01	3.74E-04	3.05E+04
TOTAL EFFECTS	Non-Transport	1.90E+07	1.65E+06	1.23E+04	6 96E+03	6.96E+02	9.16E-03	1.77E+05
	Transport	1.66E+06	1.09E+05	5.93E+02	1.73E+01	4.20E+01	4.38E-06	2.10E+04
	Total	2.07E+07	1.75E+06	1.29E+04	6 98E+03	7.38E+02	9.16E-03	1.98E+05

Figure 5: Bar Graph of Original Whole-Building Summary Measures



6.3.3 CIQS Level 3 Sorting

The Canadian Institute of Quantity Surveyors publishes an elemental format to “standardize a list of elements that enable cost analyses and control on building projects.”[42] The elements are ordered in a hierarchy of four levels. Level 1 is a “major group element”; level 2 is an “group element”; level 3 is an “element”; level 4 is a “sub-element”. For this study, it was decided to model at level 3.

This distinction allows for sufficient detail to delineate different buildings in terms of their foundational, structural and material characteristics. By stopping at level 3, the study avoids the added effort to achieve the specificity of level 4 sorting, especially since this study focuses on the product and construction process environmental impacts.

While the CIQS format is extensive, only some of the level 3 elements are included in this study. This is summarized in Table 16Table 17.

Table 16: Description of CIQS Level 3 Elements[43]

Level 3 Element	Description
A11 Foundations	This includes all structures used to transfer structural loads to the ground. Such foundations include footings, piles, caissons, and rock anchors. Also included is perimeter insulation, crawl space walls, and special dewatering measures.
A21 Lowest Floor Construction	Lowest floor construction comprises of slab-on-grade (regardless of being below- or at-grade) and any associated barrier or envelope materials
A22 Upper Floor Construction	Upper floor construction includes all structural components which rest on top of the lowest floor construction but excludes any structural components that support the roof. All walls are excluded from this level 3 element. Stair construction is included. Other typical components include columns, beams and floor slabs.
A23 Roof Construction	Roof construction comprises of the structural components that support the roof (columns or beams) and the surfaces on top of the building that are exposed to the elements. All walls are excluded from this level 3 element.
A31 Walls Below Grade	This level 3 element includes all exterior walls below grade.
A32 Walls Above Grade	This level 3 element includes all exterior walls above grade.
B11 Partitions	This level 3 element includes all inner walls (fixed, movable, and structural partitions).

---

[42] (CIQS Class Notes, 2013)

[43] (CIQS Class Notes, 2013)

6.3.4 Model Review

This study has been completed in stages. Stage 3, in particular, assessed the model for potential improvements. A number of sorting, geometric measurement, and material type and property improvements were identified. These are summarized in Table 17, Table 18, and Table 19.

Table 17: Model Improvements for CIQS Level 3 Sorting

Level 3 Element	Description of Inaccuracy	IE Inputs Affected	Improvement
A11 Foundations	Okay		
A21 Lowest Floor Construction	Okay		
A22 Upper Floor Construction	• Improper sorting of Level 3 elements between A22 and A23	• Steel HSS columns supporting Level 4 (ie. on level 3) and the roof (ie. on level 4); suspended slabs	• Create additional condition in OST and reflect changes in the IE
A23 Roof Construction			
A31 Walls Below Grade	• Improper sorting of Level 3 elements among A31, A32, and B11	• All walls and partitions	• Create additional condition in OST and reflect changes in the IE
A32 Walls Above Grade			
B11 Partitions			

Table 18: Model Improvements for Geometric Measurements

Level 3 Element	Description of Inaccuracy	IE Inputs Affected	Improvement
A11 Foundations	Okay		
A21 Lowest Floor Construction	Okay		
A22 Upper Floor Construction	Okay		
A23 Roof Construction	• Missing penthouse/roof skylights • IE input does not match OST quantity	• Create new input • Roof_Steel_Penthouse	• Add as window • Investigate further
A31 Walls Below Grade	Okay		
A32 Walls Above Grade	• OST measurements okay; quantities from OST not well reflected in IE	• Check all components	• Export OST and manually enter in dimensions
B11 Partitions	• Missing Wall_Cast-In-Place_NoEnv_200mm on ground floor • OST measurements okay; quantities from OST not well reflected in IE	• Create new input • Check all components	• Add as wall • Export OST and manually enter in dimensions

Table 19: Model Improvements for Material Type and Property

Level 3 Element	Description of Inaccuracy	IE Inputs Affected	Improvement
A11 Foundations A21 Lowest Floor Construction	Okay		
A22 Upper Floor Construction	HSS steel okay		
A23 Roof Construction	HSS steel okay		
A31 Walls Below Grade	Okay		
A32 Walls Above Grade	• Wrong wall assembly (W1 for below grade walls only)	• Concrete_Cast-in-Place_400mm_W1_AboveGrade	• Model as P3 (DWG 316-06-006)
B11 Partitions	• Spot checks of partition assemblies P3, P4, P6, and P7; all require minor edits	• Check all components	• Use Assemblies document and reference architectural drawgings
A11 Foundations	• Concrete strengths • Rebar sizes	• All components	• IE has limited inputs, choose closest value (rounded up) - see DWG 316-07-001

Identifying and actuating improvements is an iterative process—in many instances, additional areas for improvement were identified as the work on the model progressed. Hence, some improvements are not listed in the above tables. Of note, a number of HSS columns were not identified in the original model; in other instances, walls were mislabelled and modelled using an incorrect assembly. Further discussion is contained in section *6.4 Model Improvements*.

6.4 Model Improvements

This section discusses the model improvements made as part of stage 4 of the final study. While it was the intent to document every change made from the original model to the model analyzed as part of this study, inconsistent naming among the Excel, OST, and IE for the same inputs made this challenging. As such, only a brief description of the major improvements is discussed here.

6.4.1 CIQS Level 3 Sorting

The following points summarize CIQS Level 3 sorting efforts:

- To improve the sorting, it was often necessary to divide conditions between lowest floor, upper floor, and roof construction. This was also necessary for properly sorting the walls among below grade, above grade, and partition.
- In the process of locating different annotations in the OST file, it became evident that a number of elements were missed in the original model. These include:
    - HSS columns in the stairwells
    - Additional partition walls
- At the same time, comparison of the architectural drawings against the structural drawings indicated that a number of the walls were assigned an incorrect assembly. The assemblies were consequently remodelled.

6.4.2 Geometric Measurements

Overall, the quantities estimated by OST in the original model were sound. However, the transfer of quantities into Excel and then IE was not performed well. A comprehensive review of the output of OST compared against the inputs in Excel and IE was completed. Of note, almost every steel stud partition wall (B11 Partitions) had an improperly entered length in both Excel and OST. Another significant improvement included correcting the span and length dimensions of the steel joist for the penthouse.

However, a notable potential improvement was not addressed. The HSS columns throughout the building are modelled as extra basic materials. That is, they are modelled only for their production impacts without incorporation of the construction impacts. The improvement involves factoring in these with the concrete columns to obtain harmonized bay and span dimensions for both types of columns. This improvement was not carried out due to a lack of available time.

6.4.3 Material Types and Properties

While there are a number of potential material improvements that could have been carried out, the tight schedule with which to complete this extensive study prevent thorough material improvements. One of the main material improvements involves re-assessing the environmental impacts of 25 MPa concrete.

As indicated on structural drawing 316-07-001, a number of concrete elements have a design compressive strength f_c' of 25 MPa (at 28 days). These include footings, walls, and slabs. The IE has pre-set strengths of 20 MPa, 30 MPa, and 60 MPa. Since the production and usage of concrete produces significant environmental impacts, it would be utilize databases such as EcoInvent.

To complete a material improvement, the following steps could be followed. These steps are given in the context of re-modelling 30 MPa concrete into 25 MPa concrete.

1) In the IE, move the assembly with 30 MPa into a new, separate file.
2) Obtain the summary measures for the original file and the BOM for the daughter file.
3) Using information from an EPD and the original quantity of 30 MPa concrete from the BOM, determine the proportioned impacts an equivalent amount of 25 MPa concrete
4) Add these new impacts back to the original model's summary measures (in a spreadsheet program such as Excel) to obtain correct environmental impacts.

6.5 Impact Assessment

To complete the impact assessment, a number previously developed tools were utilized. Work completed by the previous author was summarized in "Input and Assumptions" documents; existing models generated in OST and IE were available for viewing and editing.

6.5.1 Input and Assumptions Document

To track the quantities and modelled assemblies between OST and IE, two spreadsheets were compiled by the previous author. An "Inputs" document indexed the quantity takeoff outputs from OST and, where necessary, converted dimensions for ease of input into IE. In addition, envelop and barrier assembly details from the "architectural construction assemblies" document is included in this spreadsheet.

However, assumptions are often required to model both the material properties as well as the envelop and barrier materials. Hence, another spreadsheet, "Assumptions" document, cross references an actual material in the building with available options in IE. The purpose of these spreadsheets is not only to document the progress of the study, but to create transparency in the data and modelling.

The combination of these spreadsheets is extensively utilized to cross-check the original model. Since model improvements have been carried out, both spreadsheets have been updated to reflect the most current and accurate building model.

6.5.2 Impact Estimator

The ASMI's Impact Estimator for Buildings is a publically available program intended for life cycle assessment of buildings in Canada. It utilizes Athena's own proprietary LCI database. According to Wayne Trusty and Scot Horst[44] the IE can be classified as a "level 2" life cycle program, one that produces assessments at the whole-building scale. The IE acts as a black box program, as the targeted user group is assumed to have limited LCA-related experience. In other words, it is not robust like other tools such as SimaPro.

Using the quantity takeoffs completed in OST, individual building assemblies can be modelled in the IE. These include common assemblies such as footings and floor slabs to more specialized assemblies such as partition walls. Once the modelling is complete, generated bill of materials and summary measure indicate the quantity of materials contained in the building and the associated environmental impacts of these products inclusive of the construction methods.

---

[44] (Trusty & Horst, 2005)

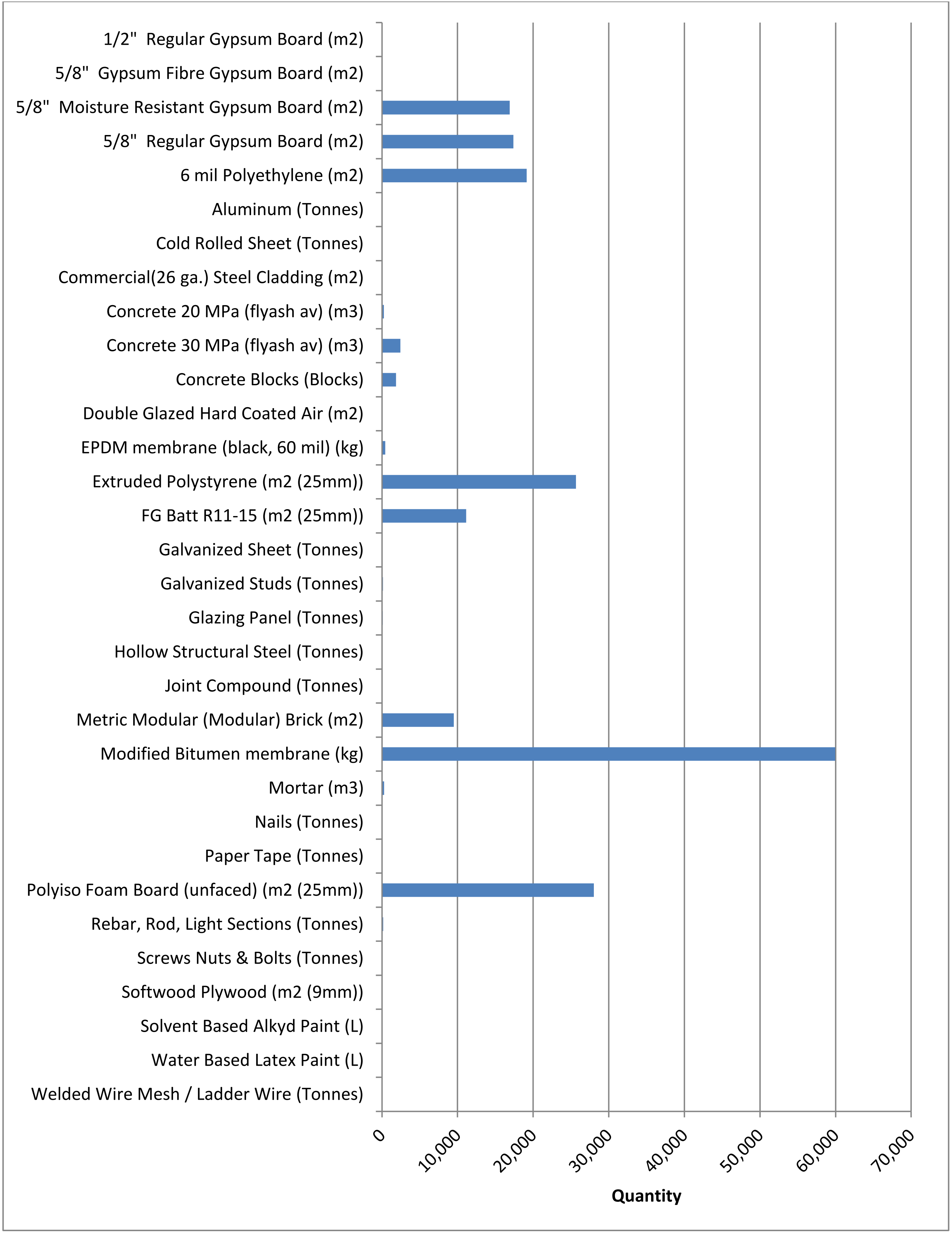
6.5.3 Revised Bill of Materials

The revised bill of materials generated for the IE model is summarized in Table 20 and Figure 6. Of note is the fact that the three largest quantities are all insulation products: modified bitumen membrane (59965.11 kg), polyiso foam board (unfaced) (28020.83m2 (25mm)), and extruded polystyrene (25656.52 m2 (25mm)).

Table 20: Revised Whole-Building Bill of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	34.92	m^2
5/8" Gypsum Fibre Gypsum Board	22.07	m^2
5/8" Moisture Resistant Gypsum Board	16895.63	m^2
5/8" Regular Gypsum Board	17395.71	m^2
6 mil Polyethylene	19153.34	m^2
Aluminum	32.59	$Tonnes$
Cold Rolled Sheet	1.83	$Tonnes$
Commercial(26 ga.) Steel Cladding	68.72	m^2
Concrete 20 MPa (flyash av)	251.12	m^3
Concrete 30 MPa (flyash av)	2432.98	m^3
Concrete Blocks	1851.48	$Blocks$
Double Glazed Hard Coated Air	0.00	m^2
EPDM membrane (black, 60 mil)	422.34	kg
Extruded Polystyrene	25656.52	$m^2\ (25mm)$
FG Batt R11-15	11135.47	$m^2\ (25mm)$
Galvanized Sheet	28.46	$Tonnes$
Galvanized Studs	129.12	$Tonnes$
Glazing Panel	88.10	$Tonnes$
Hollow Structural Steel	13.52	$Tonnes$
Joint Compound	34.28	$Tonnes$
Metric Modular (Modular) Brick	9488.20	m^2
Modified Bitumen membrane	59965.11	kg
Mortar	284.80	m^3
Nails	1.80	$Tonnes$
Paper Tape	0.39	$Tonnes$
Polyiso Foam Board (unfaced)	28020.83	$m^2\ (25mm)$
Rebar, Rod, Light Sections	156.93	$Tonnes$
Screws Nuts & Bolts	3.25	$Tonnes$
Softwood Plywood	22.16	$m^2\ (9mm)$
Solvent Based Alkyd Paint	25.53	L
Water Based Latex Paint	7.39	L
Welded Wire Mesh / Ladder Wire	1.94	$Tonnes$

Figure 6: Bar Graph of Revised Whole-Building Bill of Materials



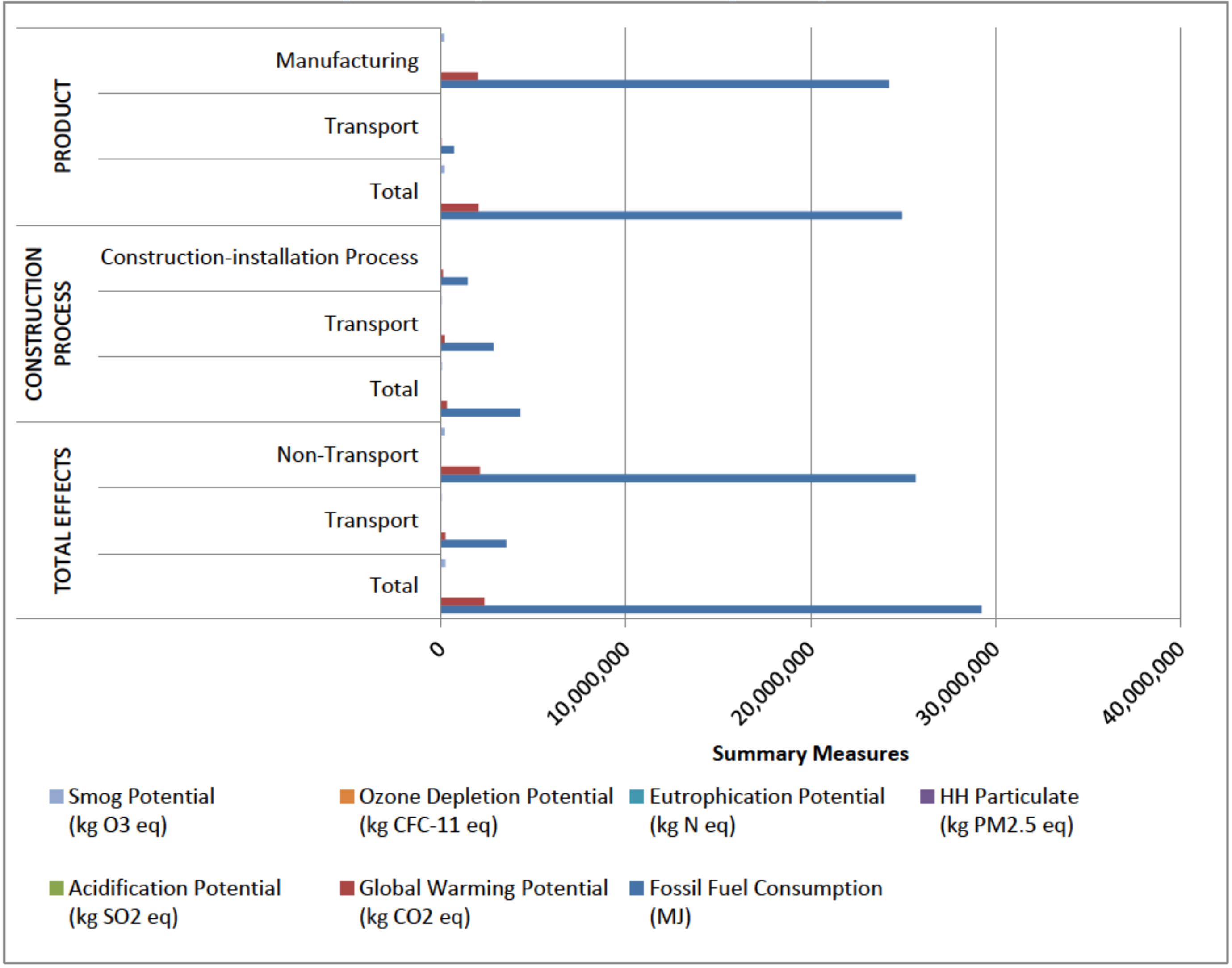
6.5.4 Revised Summary Measure Report

The revised summary measure report generated by the IE model is summarized in Table 21 and Figure 7. Fossil fuel consumption is the largest impact across all categories. Global warming potential is the second largest impact. Because this study is limited to the material (ie. product) and construction impacts, the use and end-of-life phase summary measures are omitted. These results are discussed further in Section *7 Communication of Assessment Results*.

Table 21: Revised Whole-Building Summary Measure Report

Summary Measures		**Fossil Fuel Consumption (MJ)**	**Global Warming Potential (kg CO2 eq)**	**Acidification Potential (kg SO2 eq)**	**HH Particulate (kg PM2.5 eq)**	**Eutrophication Potential (kg N eq)**	**Ozone Depletion Potential (kg CFC-11 eq)**	**Smog Potential (kg O3 eq)**
PRODUCT	Manufacturing	2.42E+07	2.00E+06	1.43E+04	7.21E+03	7.90E+02	8.74E-03	1.86E+05
	Transport	7.07E+05	4.03E+04	2.54E+02	7.10E+00	1.77E+01	1.65E-06	8.98E+03
	Total	2.49E+07	2.04E+06	1.45E+04	7.22E+03	8.08E+02	8.74E-03	1.95E+05
CONSTRUCTION PROCESS	Construction-installation Process	1.45E+06	1.18E+05	8.31E+02	1.60E+02	4.19E+01	4.24E-04	1.89E+04
	Transport	2.85E+06	2.07E+05	1.01E+03	3.07E+01	7.25E+01	8.28E-06	3.57E+04
	Total	4.30E+06	3.26E+05	1.84E+03	1.91E+02	1.14E+02	4.32E-04	5.46E+04
TOTAL EFFECTS	Non-Transport	2.57E+07	2.12E+06	1.51E+04	7.37E+03	8.32E+02	9.16E-03	2.04E+05
	Transport	3.56E+06	2.48E+05	1.26E+03	3.78E+01	9.02E+01	9.92E-06	4.47E+04
	Total	2.92E+07	2.37E+06	1.64E+04	7.41E+03	9.22E+02	9.17E-03	2.49E+05

Figure 7: Bar Graph of Revised Whole-Building Summary Measures



6.6 Net Present Value

According to UBC Properties Trust, the value of AERL at the time of completion in 2006 is CAD $10.6M. Using escalation rates from Statistics Canada, Table 327-0044, a net present value in 2013 dollars can be calculated. Since construction, AERL has gained approximately $2M in value, for a total net present value in 2013 dollars of $12.6M. This is summarized in Table 22.

Table 22: AERL Net Present Value

Year	Escalation Rate	Value
2006	1.13	$10,600,000.00
2007	1.09	$11,978,000.00
2008	0.93	$13,056,020.00
2009	0.95	$12,142,098.60
2010	1.04	$11,534,993.67
2011	1.04	$11,996,393.42
2012	1.01	$12,476,249.15
2013	–	$12,601,011.65
Net Present Value = $12,600,000.00		

7 Communication of Assessment Results

Life cycle results for the AERL building are presented in this section. A brief overview supplementary annexes is also given.

7.1 Life Cycle Results

Life cycle results (summary measures) can be exported from the IE for the whole building or individual level 3 elements for both the product and construction process stages.

In terms of whole-building life cycle results, the greatest impact is fossil fuel consumption. The second greatest impact is global warming potential. Table 21 and Figure 7, applicable to whole-building summary measures, are shown again in this section for clarity.

Table 21: Revised Whole-Building Summary Measure Report

Summary Measures		Fossil Fuel Consumption (MJ)	Global Warming Potential (kg CO2 eq)	Acidification Potential (kg SO2 eq)	HH Particulate (kg PM2.5 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O3 eq)
PRODUCT	Manufacturing	2.42E+07	2.00E+06	1.43E+04	7.21E+03	7.90E+02	8.74E-03	1.86E+05
	Transport	7.07E+05	4.03E+04	2.54E+02	7.10E+00	1.77E+01	1.65E-06	8.98E+03
	Total	2.49E+07	2.04E+06	1.45E+04	7.22E+03	8.08E+02	8.74E-03	1.95E+05
CONSTRUCTION PROCESS	Construction-installation Process	1.45E+06	1.18E+05	8.31E+02	1.60E+02	4.19E+01	4.24E-04	1.89E+04
	Transport	2.85E+06	2.07E+05	1.01E+03	3.07E+01	7.25E+01	8.28E-06	3.57E+04
	Total	4.30E+06	3.26E+05	1.84E+03	1.91E+02	1.14E+02	4.32E-04	5.46E+04
TOTAL EFFECTS	Non-Transport	2.57E+07	2.12E+06	1.51E+04	7.37E+03	8.32E+02	9.16E-03	2.04E+05
	Transport	3.56E+06	2.48E+05	1.26E+03	3.78E+01	9.02E+01	9.92E-06	4.47E+04
	Total	2.92E+07	2.37E+06	1.64E+04	7.41E+03	9.22E+02	9.17E-03	2.49E+05

Figure 7: Bar Graph of Revised Whole-Building Summary Measures

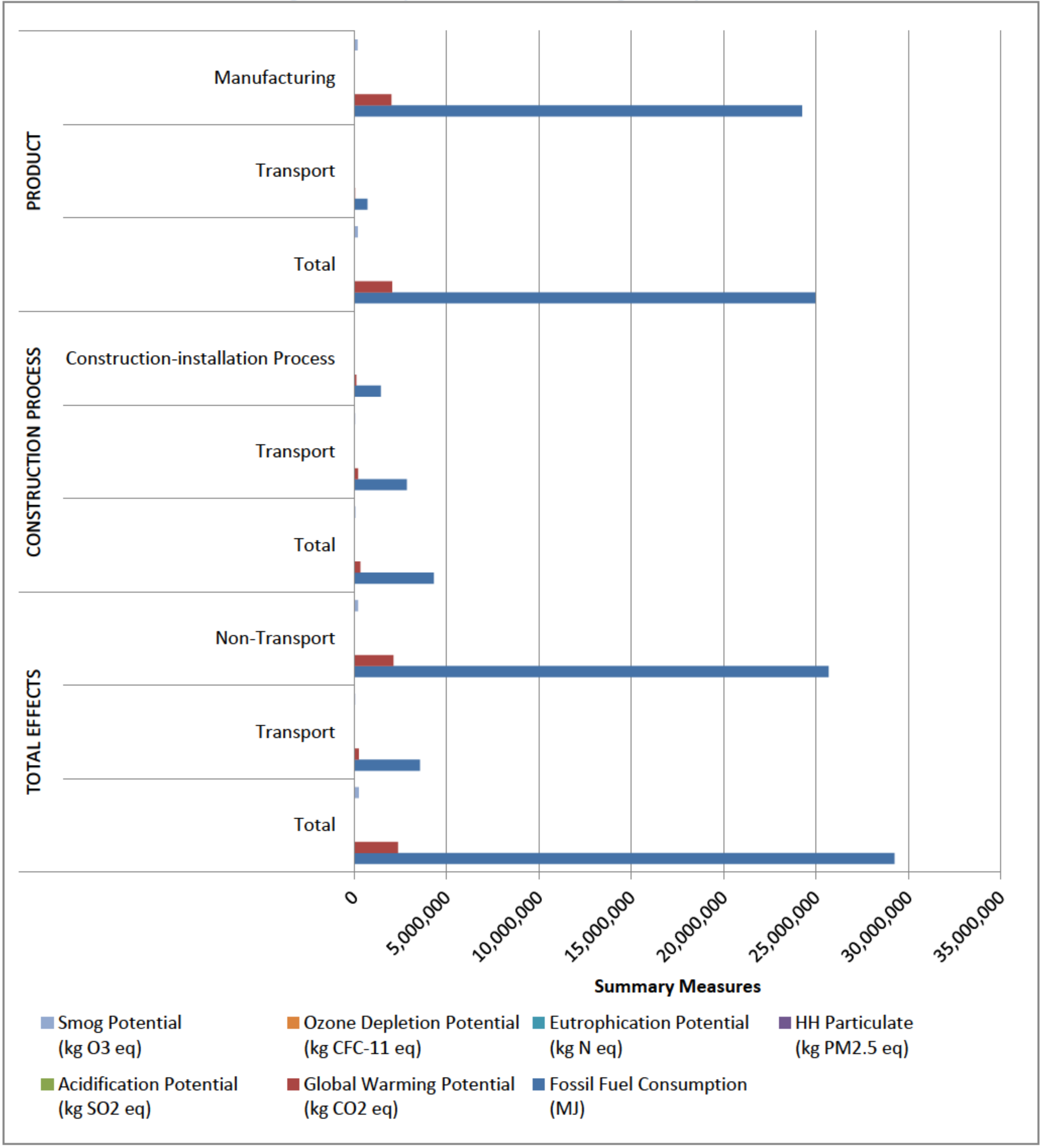


Figure 8 and Figure 9 compare the totalized absolute and normalized environmental impacts of each CIQS level 3element. The quantity of each level 3 element, as given in Table 6, is used to normalize the environmental impacts.

While Figure 8 indicates that *A32 Walls Above Grade* requires the most absolute fossil fuel consumption, Figure 9 indicates that *A23 Roof Construction* requires the most fossil fuel consumption per square meter.

Figure 8: Absolute Environmental Impacts (Totalized) by CIQS Level 3 Element

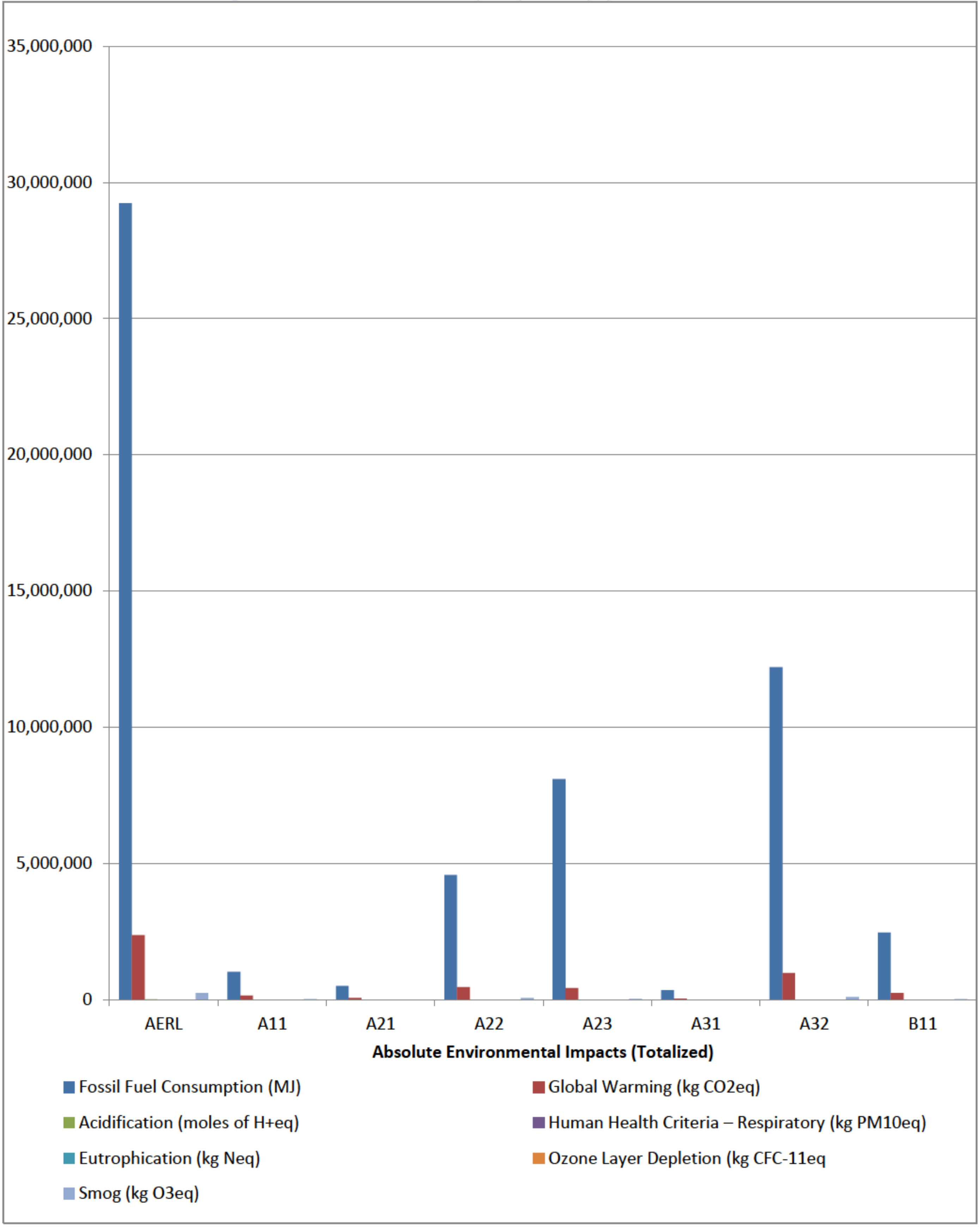
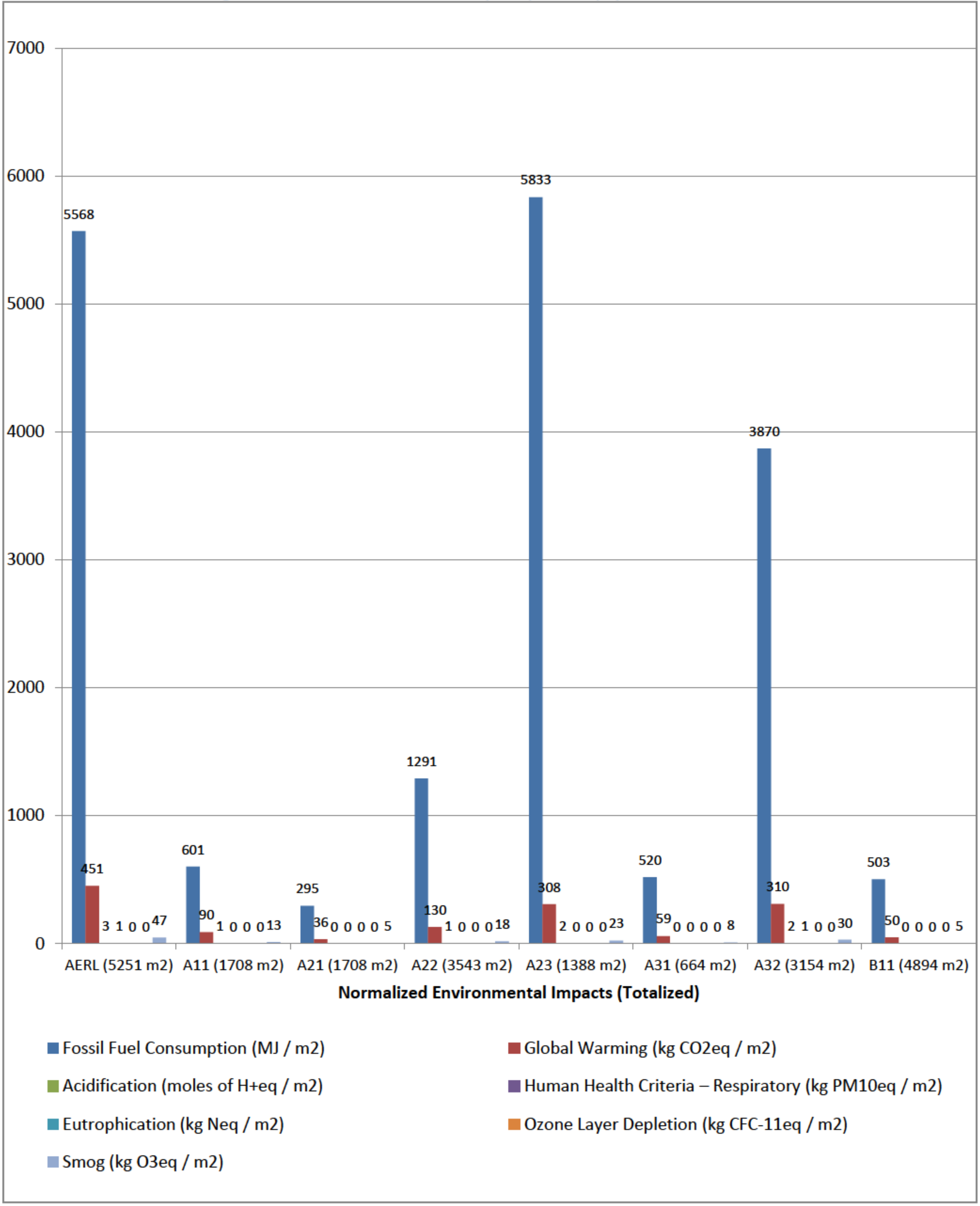


Figure 9: Normalized Environmental Impacts (Totalized) by CIQS Level 3 Element



These results suggest that the greatest environmental impacts are contained in *A23 Walls Above Grade*. This makes sense, as AERL uses concrete and steel as main structural components. The fact that both materials, especially concrete, have energy-intensive production requirements is reflected in the proportionately larger fossil fuel consumption impacts.

Table 23 summarizes the relative environmental impacts by CIQS level 3 element expressed as a percent of the total impacts for each impact category. Of note, *A32 Walls Above Grade* contributes the greatest to each impact category except for ozone layer depletion. In addition, to the above, this could be understood as additional envelop and barrier materials used in the exterior, above grade walls such that thermal and moisture excellence is achieved. This claim is plausible because the building's design incorporates many sustainable features, as discussed in Section 1.2 Identification of Building. However, further research is required to substantiate this claim.

Table 23: Relative Environmental Impacts by CIQS Level 3 Element

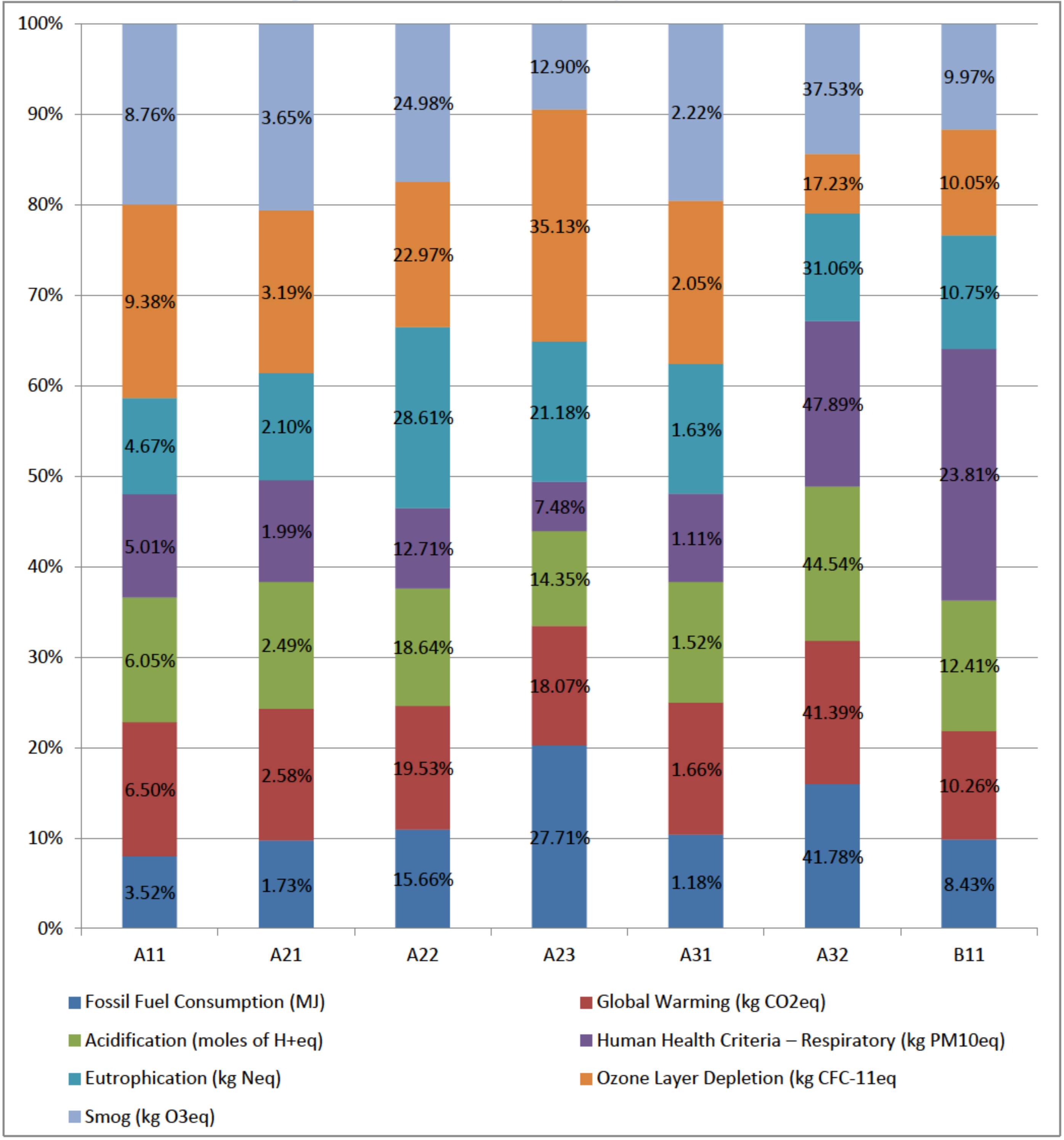
Level 3 Element	Fossil Fuel Consumption (MJ)	Global Warming Potential (kg CO2 eq)	Acidification Potential (kg SO2 eq)	HH Particulate (kg PM2.5 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O3 eq)
A11 Foundations	3.52%	6.50%	6.05%	5.01%	4.67%	9.38%	8.76%
A21 Lowest Floor Construction	1.73%	2.58%	2.49%	1.99%	2.10%	3.19%	3.65%
A22 Upper Floor Construction	15.66%	19.53%	18.64%	12.71%	28.61%	22.97%	24.98%
A23 Roof Construction	27.71%	18.07%	14.35%	7.48%	21.18%	35.13%	12.90%
A31 Walls Below Grade	1.18%	1.66%	1.52%	1.11%	1.63%	2.05%	2.22%
A32 Walls Above Grade	41.78%	41.39%	44.54%	47.89%	31.06%	17.23%	37.53%
B11 Partitions	8.43%	10.26%	12.41%	23.81%	10.75%	10.05%	9.97%
Maximum	41.78%	41.39%	44.54%	47.89%	31.06%	35.13%	37.53%
Level 3 Element	A32	A32	A32	A32	A32	A23	A32

Figure 10 summarizes the relative environmental impacts by both level 3 element and impact category. It should be noted, however, the following two items:

1) The height of each colour band in a given column represents the proportional impact of a given impact category on a given level 3 element
2) The data labels are proportioned against each impact category. That is, the sum of the data labels for each colour should total 100%.

The above two reasons justify why human health criteria appears (23.81%) for *B11 Partitions* appears disproportionate.

Figure 10: Relative Environmental Impacts by CIQS Level 3 Element



7.2 Supporting Annexes

A number of annexes have been prepared in order to further discuss and interpret the above results. *Annex A – Interpretation of Assessment Results* compares the life cycle results of the AERL building against other institutional buildings which form part of the UBC LCA Database Project. Annex *B – Recommendations for LCA Use* gives a brief discussion into what needs to be done in order to operationalize LCA in building design. *Annex D – Impact Estimator Inputs and Assumptions* lists the IE model inputs and assumptions.

8 References

Athena Sustainable Materials Institute. (2013, April). *Athena Impact Estimator for Buildings v4.2 Software and Database Overview.* Retrieved from Athena Sustainable Materials Institute: http://calculatelca.com/wp-content/uploads/2011/11/ImpactEstimatorSoftwareAndDatabaseOverview.pdf

Athena Sustainable Materials Institute. (2013). *Athena Sustainable Materials Institute*. Retrieved from Athena Sustainable Materials Institute: http://calculatelca.com/about-us/athena-sustainable-materials-institute/

Athena Sustainable Materials Institute. (2013). *Database Details.* Retrieved from Athena Sustainable Materials Institute: http://www.calculatelca.com/wp-content/uploads/2012/10/LCI_Databases_Products.pdf

Athena Sustainable Materials Institute. (2013). *Frequently Asked Questions*. Retrieved from Athena Sustainable Materials Institute: http://calculatelca.com/faqs/

Athena Sustainable Materials Institute. (2013). *History*. Retrieved from Athena Sustainable Materials Institute: http://www.athenasmi.org/about-asmi/history/

Athena Sustainable Materials Institute. (2013). *LCA Background Data*. Retrieved from Athena Sustainable Materials Institute: http://calculatelca.com/software/impact-estimator/lca-database-reports/

Athena Sustainable Materials Institute. (2013). *LCA Data & Software*. Retrieved from Athena Sustainable Materials Institute: http://www.athenasmi.org/what-we-do/lca-data-software/

Athena Sustainable Materials Institute. (2013). *LCI Databases*. Retrieved from Athena Sustainable Materials Institute: http://www.athenasmi.org/our-software-data/lca-databases/

Bird Construction Inc. (2013). *Aquatic Ecosystems Research Laboratory*. Retrieved from Bird Construction: http://www.bird.ca/Projects/project-aquatic_ecosystems_research_lab.html

Canadian Green Building Council. (2013). *UBC Aquatic Ecosystems Research Laboratory, Project 10010*. Retrieved from Canadian Green Building Council: http://www.cagbc.org/leed/projectprofile_EN.aspx

Coldstream Consulting. (2011). *EN 15978 Standard*. Retrieved from Coldstream Consulting: http://www.coldstreamconsulting.com/services/life-cycle-analysis/whole-building-lca/en-15978-standard

European Committee for Standardization. (2013, November 18). *Sustainability of construction works - Published standards.* Retrieved from European Committee for Standardization: http://www.cen.eu/cen/Sectors/TechnicalCommitteesWorkshops/CENTechnicalCommittees/Pages/Standards.aspx?param=481830&title=Sustainability%20of%20construction%20works

National Renewable Energy Laboratory. (2010, September 24). *About the LCI Database Project*. Retrieved from US Life Cycle Inventory Database: http://www.nrel.gov/lci/about.html

National Renewable Energy Laboratory. (2010, September 24). *Project Management Team*. Retrieved from US Life Cycle Inventory Database: http://www.nrel.gov/lci/project_team.html

Quantis US. (2009). *Comparative environmental life ycle assesment of hand drying systemss: the XLERATOR Hand Dryer, conventional hand dryers and paper towel systems.*

Sianchuk, R. (2009). *AERL Final Report (Draft).* Unpublished.

Standards Council of Canada. (2006, December). *National Standard of Canada: CAN/CSA-ISO 14044:06* . Ottawa: Standards Council of Canada.

Trusty, W., & Horst, S. (2005). LCA Tools Around the World. *Building Deisng & Construction - Life Cycle Assessment and Sustainability*, 12-15.

UBC Building Operations. (2013). *Design & Approvals*. Retrieved from UBC Technical Guidelines: http://www.technicalguidelines.ubc.ca/technical/design_approvals.html

UBC Building Operations. (2013). *Performance Guidelines*. Retrieved from UBC Technical Guidelines: http://www.technicalguidelines.ubc.ca/technical/performance_obj.html

UBC Properties Trust. (2009). *Aquatic Ecosystems Research Laboratory*. Retrieved from UBC Properties Trust: http://www.ubcproperties.com/portfolio_detail.php?category=Alphabetical&list=(A-G)&id=Aquatic%20Ecosystems%20Research%20Laboratory

United States Environmental Protection Agency. (2012, August 16). *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)*. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/nrmrl/std/traci/traci.html

Annex A – Interpretation of Assessment Results

This annex discusses benchmark development compares AERL against other building that are a part of the UBC LCA Database Project.

A1 – Benchmark Development

The life cycle fields are based neither on scientific enquiry nor physical laws. Because it isn't possible to evaluate the objectivity of LCA results based on scientific enquiry or physical laws, the idea of benchmarking is introduced. This process involves aggregating enough data such that the entirety of the data set gives validation to each component. In other words, if enough data points indicate the same or similar results, the average of the data is thought to be "correct" or "representative." What this means is that any given building can be said to perform better or worse than an average, representative building (ie. the benchmark). In the context of building LCAs, a benchmark for environmental performance could act as the threshold for minimum sustainable design requirements.

However, data from multiple studies should have common goal and scope, model development methods, and functional equivalence. These conditions are necessary so that data is mutually comparable. For example, if two studies have different functional units, it is not possible to compare the results of one against the other. The same is true for goal and scope and model development. When these criteria are satisfied, the benchmark can be used as precedence.

A2 – UBC Academic Building Benchmark

Figure 11, Figure 12, and Figure 13 are all comparisons of AERL's environmental performance against the benchmark's environmental performance sorted by CIQS level 3 element. The benchmark value is calculated as a mean of its supporting data. The benchmark is taken from October 21, 2013, part way through the Stage 3 submission. All three figures show impacts normalized by the functional unit—that is, impacts per square meter.

Figure 11: AERL vs. Benchmark (21-Oct-2013)

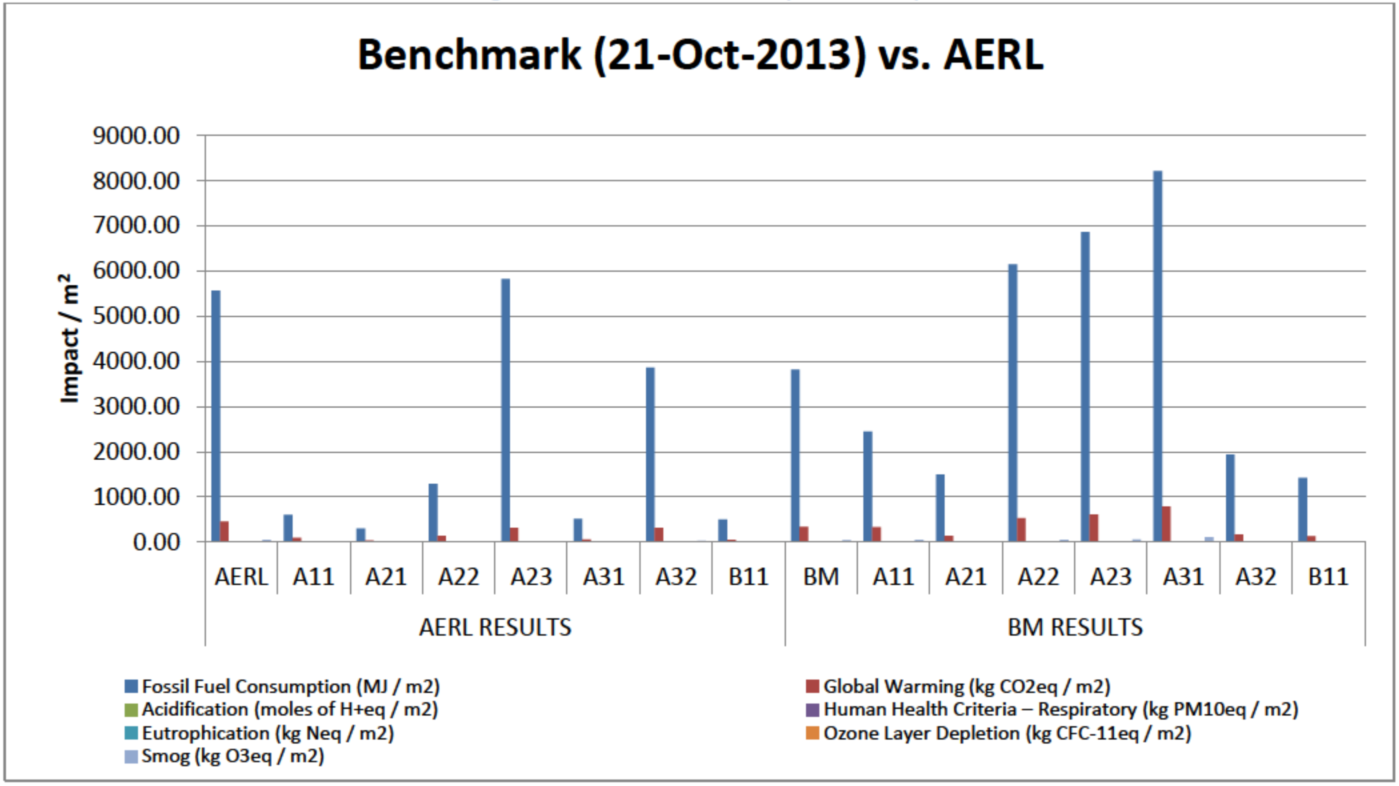
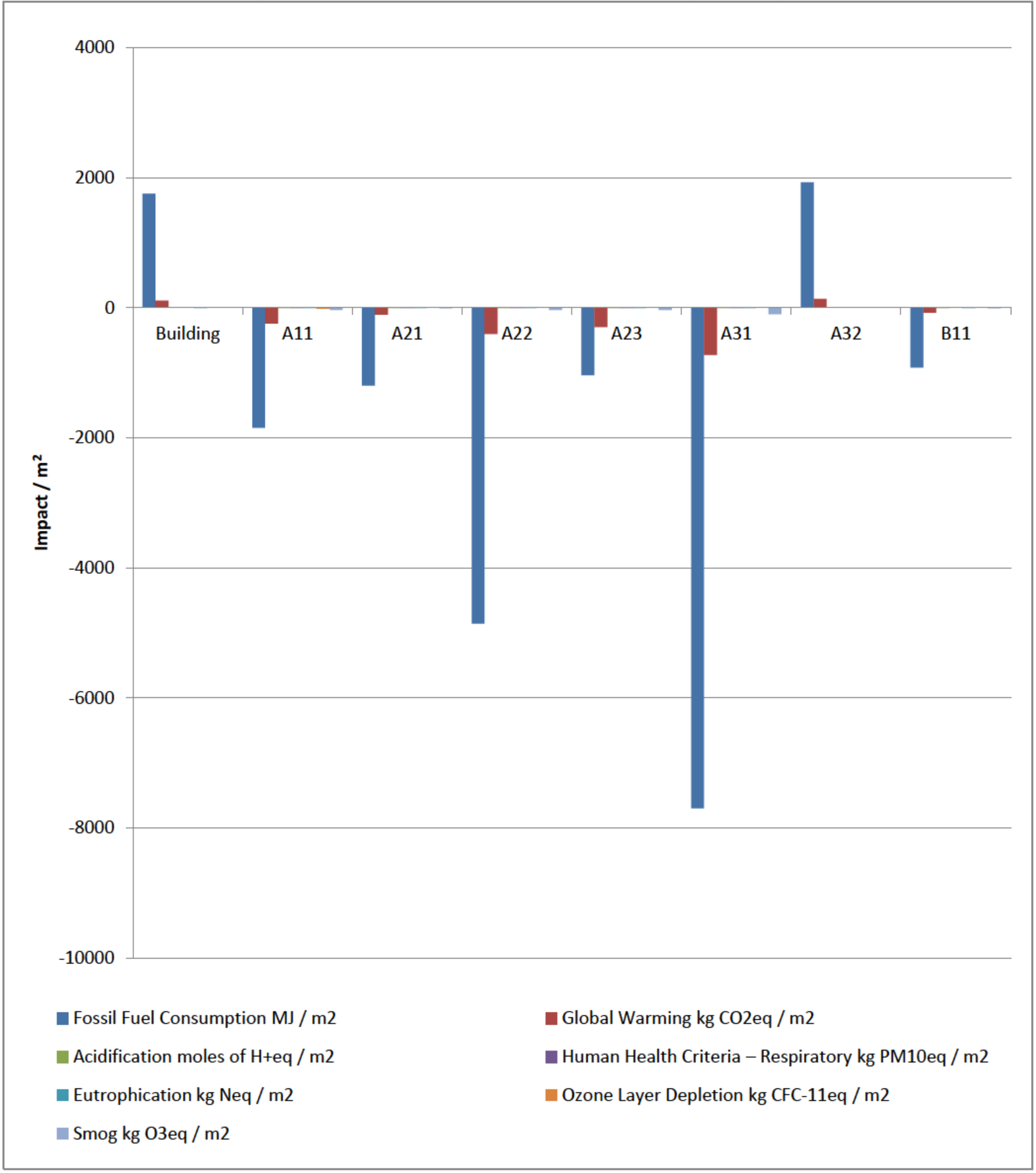


Figure 12 and Figure 13 illustrate the absolute and percent difference of AERL against the benchmark. A positive value (absolute or percent) indicates that AERL creates more impact per square meter than the benchmark; a negative value (absolute or percent) indicates that AERL creates less impact per square meter.

Figure 12: AERL Absolute Difference Relative to Benchmark (21-Oct-2013)



According to Figure 13, on average, an indicator such as global warming potential is representative of the remaining impact categories. This is the case for the following level 3 elements: A11, A21, A22, A23, and A31. That is to say, by focusing on reducing global warming potential, the net effect is to reduce impacts across all categories.

Figure 13: AERL Percent Difference Relative to Benchmark (21-Oct-2013)

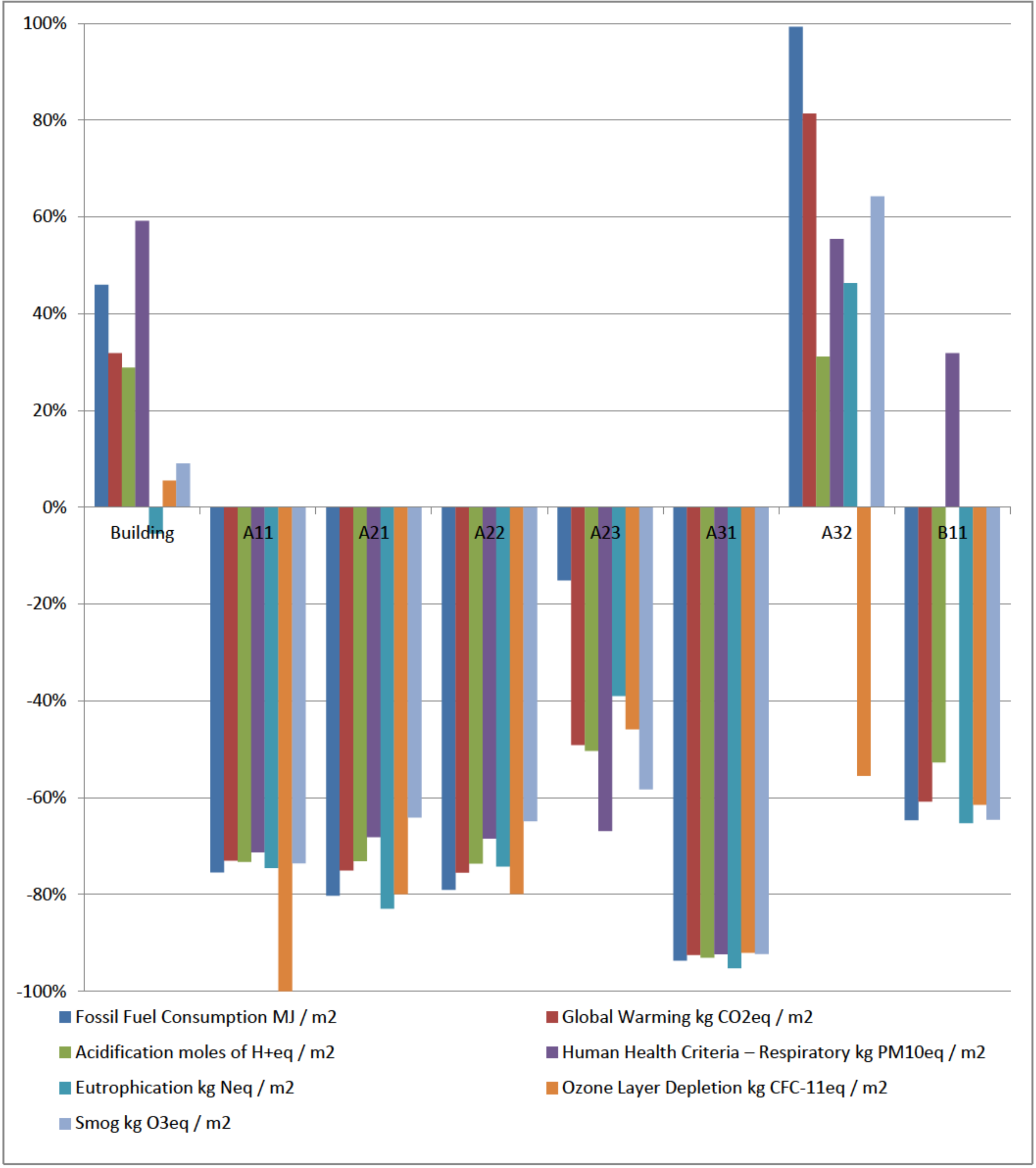
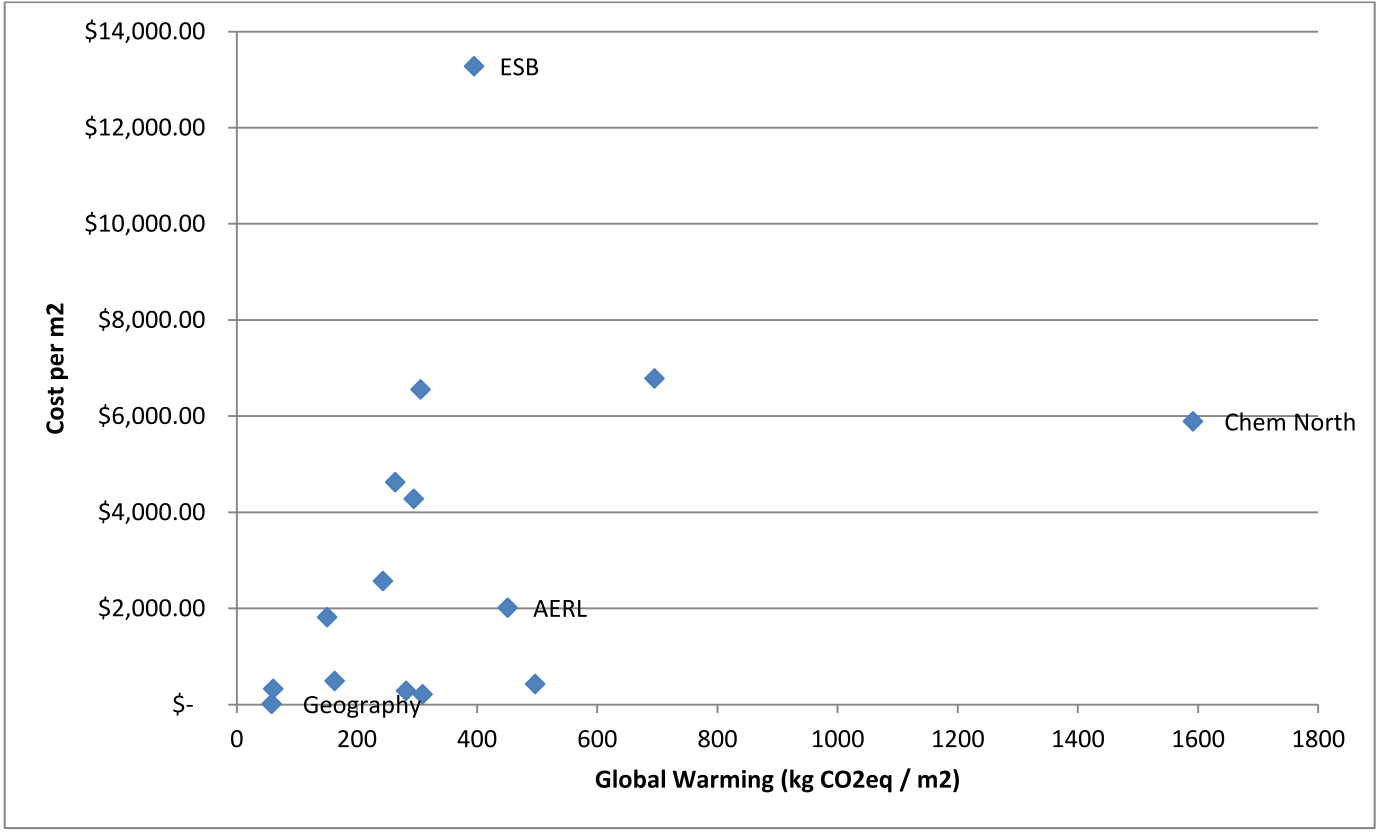


Figure 14 is a scatter plot that compares the total cost of construction against the total global warming per square meter of floor space. This figure was created on November 18, 2013, where the benchmark dataset contained information for the following buildings: AERL, Allard Hall, CEME, Chemistry North, Chemistry South, Chemistry, ESB, FSC, Geography, Henry Angus, Kaiser, Lasserre, Math, Music, and Pharmacy.

Figure 14: Total Cost vs. Total Global Warming per Square Meter for All Studies



According to Figure 14, the cost-to-global warming envelope is bounded by the Earth Sciences Building (ESB), Chemistry North, and Geography. ESB has the highest cost per kg of equivalent CO_2 while Chemistry North has the highest kg of equivalent CO_2 per unit cost. Geography has the lowest cost for the lowest amount of global warming potential.

On a per square meter of floor area basis, AERL costs approximately $\$2000/m^2$, which corresponds to approximately $450\ kg\ CO2eq\ /m^2$. This represents a design that is cost efficient yet still produces minimal global warming impacts.

Annex B – Recommendations for LCA Use

This annex gives a number of recommendations for operationalizing LCA in building design.

Adoption and Adherence to Standards

In the same way that benchmarking requires equivalence in goal and scope, model development, and function units among other criteria, building LCA studies should adhere to a unified and standardized set of criteria. For this study, EN 15978 was only partially observed. Because LCA, and building LCA in particular, is still an emerging field in North America, it is important to create precedence for environmental performance. As discussed in Annex A, precedence is achieved through benchmarking, and benchmarking is achieved through standardizing studies. Hence, one recommendation is to create or adopting existing standards for use in building LCA in North America.

Application of LCA to Building Design

One of the barriers to sustainable design is the high capital cost of improved energy systems, in-house wastewater treatment systems, and low-volatile paints among other design options. However, because building LCA strives to assess the product from cradle to grave, it can be used as a key negotiating tool with stakeholders. That is, LCA is one tool that can help rationalize higher initial costs of an improved design by quantifying long term returns (economic, environmental, and social). Because buildings are often publically funded, one recommendation for LCA operationalization would be to incorporate LCA studies into bid requirements.

Data Quality and Availability

The quality of an LCA study is only as good as the source data from which it is modelled. In order to ensure high data quality and availability, government initiatives could be developed to collect, analyze and publish data. Statistics Canada is a prime example of a government body that produces a wide range of high quality data. One recommendation would be expand the mandate of existing organizations such as Statistics Canada to incorporate LCA data, or to publically fund private initiatives such as the Athena Sustainable Materials Institute.

Public Understanding of LCA Results

Because any given LCA study requires knowledge of chemistry, economics and ecology among other fields, it is often difficult for the public to fully understand and utilize LCA results for decision making. In addition, because any given impact assessment method uses multiple indicators, it is often difficult for the public to fully adopt a wide range of environmental issues. By choosing a single indicator, or creating a weighting process among the indicators, LCA results could be better communicated to the public. In Europe, the decision to focus on global warming impacts seems prudent. Not only is global warming an issues that most are familiar with, many governments have adopted greenhouse gas emission reduction protocols. Hence, one recommendation is for North America to adopt a similar focus when evaluating the results of an LCA study.

Annex C – Author Reflection

This annex briefly discusses and comments on LCA, sustainability, CIVL 498C, and the final project.

C1 – Prior Exposure to LCA and Sustainability

While I have a combination of coursework and work experience related to sustainability, only the coursework is discussed here. I have no (formal) prior exposure to LCA.

Table 24: Sustainability in Prior Courses

Courses/Coursework	Description
APSC 201 "Technical Communication"	• Wrote my term paper on the Centre for Interactive Research on Sustainability (CIRS) • Interviewed Alberto Cayuela (in the AERL building) • This report gave an introductory look to green building design elements; in the case of CIRS, including but not limited to the following: ○ Water management ▪ Rainwater harvesting ▪ Wastewater management and treatment ▪ High efficiency water fixtures and plumbing ○ Energy management ▪ Photovoltaic panels ▪ Ground source heat pump ▪ Waste heat reuse ○ Indoor environmental quality ▪ Ventilation ▪ Daylighting ○ Resource conservation ▪ Sustainable building materials ▪ Modularity of partition walls
CIVL 201 "Civil Engineering"	Among other activities, a few highlights: • UBC green building tours – ie. Life Sciences – LEED certification • Commentary on a public lecture by Stewart Brand – "Rethinking Green" (Liu Institute for Global Issues, October 5, 2010)
CIVL 445 "Engineering Design and Analysis I"	This year's capstone project focuses on a redevelopment proposal for the UBC botanical gardens; one significant feature of botanical gardens is the emphasis on conservation and sustainability – my project had elements of sustainability integrated into the proposal: • Drip irrigation system / bio filtration channel • Green features for the multi-storey parkade • Green features for the overhead walkway

C2 – Course and Final Project Highlights

This section discusses course and final project highlights.

Course Highlights

- The interdisciplinary nature of the life cycle approaches. In the context of civil engineering, this means opportunities to engage in higher level thinking beyond design codes and checks.
- Discussion of sustainability: the interaction between the built environment and the natural environment.
- The accounting methodology of LCA appeals to my interests in defining and categorizing information in a standardized way.
- Completion of this project has been an interesting introduction into the field of life cycle approaches (social assessment, environmental assessment, and costing)
- The timeline for the completion of the report has been rushed. I would have much appreciated better time planning, as the fourth year civil course load is hardly insignificant, especially at the end of semester. The level of effort to turn over a report of this magnitude given just 3 weeks' notice is significant beyond the workload demands of all my other courses combined.

Final Project Highlights

- Opportunity to learn about engineering structures, architectural finishes and assemblies
- Exposure to green building design element: the effect of "over"-glazing, passive ventilation systems, building modularity
- Participation in a study that has the potential for far reaching impacts – these studies may create precedent for future UBC building design and construction
- Having interviewed Alberto Cayuela in AERL two years ago about the CIRS building, this project brings my interaction with the building full circle.

C3 – LCA and Sustainability Commentary

It appears that LCA has the potential to provide a consistent, reliable, and accurate quantification of sustainability. However, this accounting method is feasible only for those with enough interest and financial resources to afford it. That is, LCA seems to be largely unavailable to those who cannot afford to pay or uninteresting to those who do not understand its purpose and expression.

While the idea of sustainability has been mentioned in courses over the significant portion of my undergraduate experience, this has been the only course that has delineated the idea that being "more sustainable" is not the same as "more *less* unsustainable". From my perspective, "actual" sustainability gains means quantifying a net zero or net positive environmental performance. In other words, being less unsustainable from any given reference point without achieving a net zero or positive impact is still being unsustainable.

C4 – CEAB Graduate Attributes

A related component of this course was to track the development of Canadian Engineering Accreditation Board graduate attributes. These attributes are summarized in Table 25 for this specific final project. The following content code is applied to the matrix:

N/A	not applicable
I	introduced
D	developed
A	applied
ID	introduced & developed
IA	introduced & applied
DA	developed & applied
IDA	introduced, developed & applied

Table 25: CEAB Graduate Attributes

Graduate Attribute		Description	Content Code	Final Project Experience
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A	This project utilized basic arithmetic for summary measure calculations and analysis. Knowledge of the natural sciences (reaction mechanisms, chemistry nomenclature) was applied to understand the relation between emissions and impact potential. Knowledge of construction drawings was applied for quantity takeoffs.
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	DA	This project provides new learning material for which problem analysis is developed and applied. For this project, the engineering problem is the quantification of the environmental performance of AERL. The resulting solution has involved utilizing life cycle assessment with TRACI impact measures categorized by CIQS Level 3 elements all modelled by the ASMI's Impact Estimator program.
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.	N/A	This final project is research and modelling focused. There is significant interpretation (of drawings); however, there is no significant investigation potential.
4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	N/A	This final project is research and modelling focused. There is significant interpretation (of drawings); however, there is no significant design potential.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	A	The use of modelling programs such as OST and IE are the main engineering tools utilized in this project. Their usage involves a substantial understanding of the underlying assumptions, applicability of results, and model limitations.
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	A	This project presented the opportunity to work with other students with reference to creation of benchmark results.
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	DA	The life cycle approaches can be thought of as an accounting method with specific terminology and applicability. The final project has been an opportunity to interpret and communicate complex ideas such as functional unit, temporal uncertainty, elemental sorting, and characterization factors among other ideas.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	A	This project highlighted the requirement for engineers to understand the short- and long-term implications associated with engineering decisions, especially in the context of environmental impacts and performance of engineering products.
9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	DA	This project further developed my understanding of the environmental impacts and performance of buildings on the environment. This project was delivered in the context of one method to quantify sustainability—life cycle analysis.
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	A	This final project involved preparing a final report; appropriate citations and credit are given for referenced information and ideas.
11	Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	IDA	A brief introduction into engineering calculations for net present value to project constructed costs (2006) to current costs (2013).
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	DA	This project has been an opportunity to learn more about life cycle approaches while applying classroom knowledge through modelling a real-life building in a commercially available program to quantify environmental performance.

Annex D – Impact Estimator Inputs and Assumptions

Table 26: Sorted CIQS Level 3 Impact Estimator Inputs

Assembly Group	Assembly Name	Input Fields	Known/Measured	IE Inputs
A11.1 Foundations	A11.1.1 Footing_F1	Length (ft)	18.80	18.80
		Width (ft)	9.40	15.58
		Thickness (in)	31.50	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#7	#6
	A11.1.2 Footing_F2	Length (ft)	34.00	34.00
		Width (ft)	8.50	12.35
		Thickness (in)	27.60	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#7	#6
	A11.1.3 Footing_F3	Length (ft)	19.20	19.20
		Width (ft)	4.80	4.80
		Thickness (in)	17.70	17.70
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5 & 6	#6
	A11.1.4 Footing_F4	Length (ft)	59.40	59.40
		Width (ft)	4.10	4.10
		Thickness (in)	13.80	13.80
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5	#5
	A11.1.5 Footing_F5	Length (ft)	54.90	54.90
		Width (ft)	6.10	6.97
		Thickness (in)	21.70	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average

		Rebar	#6	#6
	A11.1.6 Footing_F6	Length (ft)	13.10	13.10
		Width (ft)	6.60	8.20
		Thickness (in)	23.60	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#6	#6
	A11.1.7 Footing_F7	Length (ft)	14.80	14.80
		Width (ft)	5.40	5.40
		Thickness (in)	17.70	17.70
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5 & 6	#6
	A11.1.8 Footing_F8	Length (ft)	14.40	14.40
		Width (ft)	7.20	9.70
		Thickness (in)	25.60	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#6	#6
	A11.1.9 Footing_F9	Length (ft)	5.40	5.40
		Width (ft)	4.10	4.10
		Thickness (in)	17.70	17.70
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5	#5
	A11.1.10 Footing_F10	Length (ft)	12.80	12.80
		Width (ft)	6.40	7.31
		Thickness (in)	21.70	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5	#5
	A11.1.11 Footing_SF1	Length (ft)	315.23	315.23
		Width (ft)	2.00	2.00
		Thickness (in)	9.80	9.80
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average

		Rebar	#5	#5
	A11.1.12 Footing_SF2	Length (ft)	31.38	31.38
		Width (ft)	2.60	2.60
		Thickness (in)	9.80	9.80
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5	#5
	A11.1.13 Footing_1400mm_LeftBasement	Length (ft)	52.73	52.73
		Width (ft)	52.73	152.97
		Thickness (in)	55.12	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#7	#6
	A11.1.14 Footing_700mm_SmallLeftBasement	Length (ft)	18.41	18.41
		Width (ft)	18.41	26.71
		Thickness (in)	27.56	19.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#7	#6
A21.1 Foundations	A21.1.1 SOG_125mm	Length (ft)	104.65	116.08
		Width (ft)	104.65	116.08
		Thickness (in)	4.92	4.00
		Concrete (psi)	3000.00	3000.00
		Concrete flyash %	-	average
	A21.1.3 SOG_150mm	Length (ft)	51.26	50.86
		Width (ft)	51.26	50.86
		Thickness (in)	7.87	8.00
		Concrete (psi)	3000.00	3000.00
		Concrete flyash %	-	average
	A21.1.2 SOG_200mm	Length (ft)	69.32	84.23
		Width (ft)	69.32	84.23
		Thickness (in)	5.91	4.00
		Concrete (psi)	3000.00	3000.00
		Concrete flyash %	-	average
A22.1 Foundations	A22.1.1 Stairs_Concrete_TotalLength	Length (ft)	207.03	207.03
		Width (ft)	3.67	3.67

		Thickness (in)	14.00	14.00
		Concrete (psi)	4000.00	4000.00
		Concrete flyash %	-	average
		Rebar	#5	#5
A22.2 Columns and Beams	A22.2.1 Column_Concrete_Beam_N/A_Basement	Number of Beams	0.00	0.00
		Number of Columns	6.00	6.00
		Floor to floor height (ft)	12.00	12.00
		Bay sizes (ft)	16.17	16.17
		Supported span (ft)	16.17	16.17
		Live load (psf)	-	75.00
	A22.2.2 Column_Concrete_Beam_N/A_GroundLevel	Number of Beams	0.00	0.00
		Number of Columns	38.00	38.00
		Floor to floor height (ft)	12.00	12.00
		Bay sizes (ft)	17.35	17.35
		Supported span (ft)	17.35	17.35
		Live load (psf)	-	75.00
	A22.2.3 Column_Concrete_Beam_N/A_Level2	Number of Beams	0.00	0.00
		Number of Columns	41.00	41.00
		Floor to floor height (ft)	12.00	12.00
		Bay sizes (ft)	17.92	17.92
		Supported span (ft)	17.92	17.92
		Live load (psf)	-	75.00
	A22.2.4 Column_Concrete_Beam_N/A_Level3	Number of Beams	0.00	0.00
		Number of Columns	45.00	45.00
		Floor to floor height (ft)	12.00	12.00
		Bay sizes (ft)	17.10	17.10
		Supported span (ft)	17.10	17.10
		Live load (psf)	-	75.00
A22.3 Floors	A22.3.1 Floor_ConcreteSuspendedSlab_200mm	Floor Width (ft)	1271.28	1271.28
		Span (ft)	30.00	30.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Life load (psf)	-	75.00
A22.4 Extra Basic Materials	A22.4.1 XBM_Columns_HSS_(UpperFloor)	Hollow Structural Steel (Tons)	-	5.64

A23.1 Columns and Beams	A23.1.1 Column_Concrete_Beam_N/A_Level4	Number of Beams	0.00	0.00
		Number of Columns	45.00	45.00
		Floor to floor height (ft)	12.00	12.00
		Bay sizes (ft)	17.10	17.10
		Supported span (ft)	17.10	17.10
		Live load (psf)	-	75.00
A23.2 Roofs	5.1.1 Roof_ConcreteSuspendedSlab_200mm	Roof Width (ft)	379.37	379.05
		Span (ft)	30.00	30.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Life load (psf)	-	75.00
		Category	Roof Envelopes	Roof Envelopes
		Material	Standard Modified Bitumen Membrane 2 ply	Standard Modified Bitumen Membrane 2 ply
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Polyisocyanurate Foam	Polyisocyanurate Foam
		Thickness	3.93	3.93
		Category	Vapour Barrier	Vapour Barrier
		Material	-	Polyethylene 6 mil
		Thickness	-	-
	5.2.1 Roof_SteelJoist_Penthouse	Roof Width (ft)	204.85	204.85
		Roof Length (ft)	17.35	17.35
		Decking Type	Dens Deck Roof Board	-
		Decking Thickness	5/8	5/8
		Steel Gauge	-	18.00
		Joist Type	-	1 5/8 x 6
		Joist Spacing	-	16.00
		Category	Roof Envelopes	Roof Envelopes
		Material	Standard Modified Bitumen Membrane 2 ply	Standard Modified Bitumen Membrane 2 ply
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Dens-GlassGoldSheathing	Gypsum Moisture Resistant 5/8"
		Thickness	-	-

		Category	Insulation	Insulation
		Material	Polyisocyanurate Foam	Polyisocyanurate Foam
		Thickness	3.93	3.93
		Category	Vapour Barrier	Vapour Barrier
		Material	-	Polyethylene 6 mil
		Thickness	-	-
A23.3 Extra Basic Materials	A22.4.1 XBM_Columns_HSS_(RoofConstruction)	Hollow Structural Steel (Tons)	-	7.29
A31.1 Walls (Cast-in-Place)	A31.1.1 Wall_Cast-in-Place_150mm	Length (ft)	27.30	20.48
		Height (ft)	12.00	12.00
		Thickness (in)	6.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	A31.1.2 Wall_Cast-in-Place_W1_200mm	Length (ft)	331.87	331.87
		Height (ft)	12.00	12.00
		Thickness (in)	8.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
		Category	Insulation	Insulation
		Material	Rigid Insulation	Polystyrene Extruded
		Thickness	1.5"	1.5"
	A31.1.3 Wall_Cast-in-Place_W2_200mm	Length (ft)	18.00	18.00
		Height (ft)	12.00	12.00
		Thickness (in)	8.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
		Category	Vapour Barrier	Vapour Barrier
		Material	Polyethylene 6 mil	Polyethylene 6 mil
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board

		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	150mm	150mm
	A31.1.4 Wall_Cast-in-Place_W1_400mm	Length (ft)	218.49	291.32
		Height (ft)	12.00	12.00
		Thickness (in)	16.00	12.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
		Category	Insulation	Insulation
		Material	Polystyrene Extruded	Polystyrene Extruded
		Thickness	1.5"	1.5"
A32.1 Walls (Cast-in-Place)	A32.1.1 Wall_Cast-in-Place_300mm	Length (ft)	12.24	12.24
		Height (ft)	12.00	12.00
		Thickness (in)	12.00	12.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	A32.1.2 Wall_Cast-In-Place_W3_200mm	Length (ft)	394.48	394.48
		Height (ft)	12.00	12.00
		Thickness (in)	8.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
		Category	Cladding	Cladding
		Material	Brick - Modular (metric)	Brick - Modular (metric)
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Polystyrene Extruded	Polystyrene Extruded
		Thickness	2.64"	2.64"
		Category	Vapour Barrier	Vapour Barrier
		Material	-	Polyethylene 6 mil

		Thickness	-	-
A32.2 Walls (Concrete Block Wall)	A32.2.1 Wall_ConcreteBlock_W4_200mm	Length (ft)	12.92	12.92
		Height (ft)	12.00	12.00
		Rebar	#4	#4
		Category	Cladding	Cladding
		Material	Brick - Modular (metric)	Brick - Modular (metric)
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Polystyrene Extruded	Polystyrene Extruded
		Thickness	2.64"	2.64"
		Category	Vapour Barrier	Vapour Barrier
		Material		Polyethylene 6 mil
		Thickness	-	-
		Number of Windows	2.00	2.00
		Total Window Area (ft2)	32.00	32.00
		Frame Type	Fixed, Aluminum Frame	Fixed, Aluminum Frame
		Number of Doors	1.00	16.00
		Door Type	-	Aluminum Exterior Door, 80% glazing
	A32.2.2 Wall_ConcreteBlock_W4_200mm_ ShortBrickAddIn_Length	Length (ft)	186.01	186.01
		Height (ft)	3.58	3.58
		Rebar	#4	#4
		Category	Cladding	Cladding
		Material	Brick - Modular (metric)	Brick - Modular (metric)
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Polystyrene Extruded	Polystyrene Extruded
		Thickness	2.64"	2.64"
		Category	Vapour Barrier	Vapour Barrier
		Material		Polyethylene 6 mil
		Thickness	-	-
A32.3 Walls (Curtain Wall)	2.3.1 Wall_CurtainWall_AllGlazing	Length (ft)	830.12	830.12
		Height (ft)	12.00	12.00
		Percent Viewable Glazing	100.00	100.00
		Percent Spandrel Panel	0.00	0.00
		Thickness of Insulation (in)	2.64"	2.64"
		Spandrel Type (Metal/Glass)	Metal	Metal

		Number of Doors	12.00	12.00
		Door Type	-	Aluminum Exterior Door, 80% glazing
	2.3.2 Wall_CurtainWall_MetalSpandrel	Length (ft)	737.00	737.00
		Height (ft)	12.00	12.00
		Percent Viewable Glazing	75.00	75.00
		Percent Spandrel Panel	25.00	25.00
		Thickness of Insulation (in)	2.64"	2.64"
		Spandrel Type (Metal/Glass)	Metal	Metal
		Number of Doors	1.00	1.00
		Door Type	-	Aluminum Exterior Door, 80% glazing
A32.4 Walls (Steel Stud)	2.4.3 Wall_SteelStud_W5	Length (ft)	710.42	710.42
		Height (ft)	12.00	12.00
		Sheathing Type	Dens-GlassGoldSheathing	None
		Stud Spacing	-	16oc
		Stud Weight	-	Heavy (20Ga)
		Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Number of Windows	128.00	128.00
		Total Window Area (ft2)	2151.68	2151.68
		Frame Type	Fixed, Aluminum Frame	Fixed, Aluminum Frame
		Glazing Type	-	Low E Tin Glazing
		Category	Cladding	Cladding
		Material	Brick - Modular (metric)	Brick - Modular (metric)
		Thickness	-	-
		Category	Insulation	Insulation
		Material	CavityMateUltra	Polystyrene Extruded
		Thickness	2.64"	2.64"
		Category	Vapour Barrier	Vapour Barrier
		Material		Polyethylene 6 mil
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"

		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Dens-GlassGoldSheathing	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
	2.4.4 Wall_SteelStud_W5_SteelCladding-Add-in_Length	Length (ft)	175.58	175.58
		Height (ft)	3.83	3.83
		Sheathing Type	Dens-GlassGoldSheathing	None
		Stud Spacing	-	16oc
		Stud Weight	-	Heavy (20Ga)
		Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Category	Cladding	Cladding
		Material	Steel Cladding - Commercial (26 ga.)	Steel Cladding - Commercial (26 ga.)
		Thickness	-	-
		Category	Insulation	Insulation
		Material	CavityMateUltra	Polystyrene Extruded
		Thickness	2.64"	2.64"
		Category	Vapour Barrier	Vapour Barrier
		Material		Polyethylene 6 mil
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Dens-GlassGoldSheathing	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
B11.1 Walls (Cast-in-Place)	B11.1.1 Wall_Cast-in-Place_NoEnv_200mm	Length (ft)	36.28	36.28
		Height (ft)	12.00	12.00
		Thickness (in)	8.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	B11.1.2 Wall_Cast-in-Place_200mm_P1	Length (ft)	113.75	113.75
		Height (ft)	12.00	12.00

		Thickness (in)	8.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	B11.1.3 Wall_Cast-in-Place_200mm_P3	Length (ft)	39.55	39.55
		Height (ft)	12.00	12.00
		Thickness (in)	8.00	8.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	B11.1.4 Wall_Cast-in-Place_250mm	Length (ft)	38.83	32.36
		Height (ft)	12.00	12.00
		Thickness (in)	10.00	12.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	B11.1.5 Wall_Cast-in-Place_400mm_P3	Length (ft)	144.13	192.18
		Height (ft)	12.00	12.00
		Thickness (in)	16.00	12.00
		Concrete (psi)	3500.00	4000.00
		Concrete flyash %	-	average
		Rebar	#4	#5
	B11.2.1 Wall_ConcreteBlock_P2_Partition	Length (ft)	70.98	70.98
		Height (ft)	12.00	12.00
		Rebar	#4	#4
		Number of Doors	3.00	3.00
		Door Type	-	Steel Interior Door, 50% glazing
B11.3 Walls (Curtain Wall)	B11.3.1 Wall_CurtainWall_TypeSF1	Length (ft)	788.29	788.29
		Height (ft)	12.00	12.00
		Percent Viewable Glazing	-	99.00
		Percent Spandrel Panel	-	1.00
		Thickness of Insulation (in)	-	0.10

		Spandrel Type (Metal/Glass)	Metal	Metal
		Number of Doors	16.00	16.00
		Door Type	-	Steel Interior Door, 50% glazing
B11.4 Walls (Steel Stud)	B11.4.1 Wall_SteelStud_P3_Partition	Length (ft)	500.72	250.36
		Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 1 13/16	1 5/8 x 3 5/8
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	-	Gypsum Board
		Material	-	Gypsum Regular 5/8"
		Thickness	-	-
	B11.4.2 Wall_SteelStud_P4_Partition	Length (ft)	615.47	615.47
		Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 3 5/8	1 5/8 x 3 5/8
		Number of Doors	60.00	60.00
		Door Type	-	Steel Interior Door, 50% glazing
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	3.62
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
	B11.4.3 Wall_SteelStud_P5_Partition	Length (ft)	316.97	316.97
		Height (ft)	12.00	12.00

		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Number of Doors	16.00	16.00
		Door Type	-	Steel Interior Door, 50% glazing
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	3.62
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
	B11.4.4 Wall_SteelStud_P6_Partition	Length (ft)	1039.14	1039.14
		Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 3 5/8	1 5/8 x 3 5/8
		Number of Doors	23.00	23.00
		Door Type	-	Steel Interior Door, 50% glazing
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	3.62
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
	B11.4.5	Length (ft)	233.73	233.73

	Wall_SteelStud_P7_Partition	Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 3 5/8	1 5/8 x 3 5/8
		Number of Doors	13.00	13.00
		Door Type	-	Steel Interior Door, 50% glazing
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Moisture Resistant 5/8"	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	3.62
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Moisture Resistant 5/8"	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
	B11.4.6 Wall_SteelStud_P8_Partition	Length (ft)	186.17	186.17
		Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Number of Doors	7.00	7.00
		Door Type	-	Steel Interior Door, 50% glazing
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Moisture Resistant 5/8"	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	3.62
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-

		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Moisture Resistant 5/8"	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
	B11.4.7 Wall_SteelStud_P9_Partition	Length (ft)	162.85	162.85
		Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Number of Doors	3.00	3.00
		Door Type	-	Steel Interior Door, 50% glazing
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	3.62
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Moisture Resistant 5/8"	Gypsum Moisture Resistant 5/8"
		Thickness	-	-
	B11.4.8 Wall_SteelStud_P10_Partition	Length (ft)	14.24	14.24
		Height (ft)	12.00	12.00
		Sheathing Type	None	None
		Stud Spacing	16 oc	16oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	1 5/8 x 3 5/8	1 5/8 x 3 5/8
		Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 5/8"	Gypsum Regular 1/2"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Fiberglass Batt	Fiberglass Batt
		Thickness	3.62	1.36
		Category	Gypsum Board	Gypsum Board

		Material	Gypsum Regular 5/8"	Gypsum Regular 1/2"
		Thickness	-	-
	B11.4.9 Wall_SteelStud_Type29	Length (ft)	310.49	310.49
		Height (ft)	3.42	3.42
		Sheathing Type	-	None
		Stud Spacing	-	24oc
		Stud Weight	-	Light (25Ga)
		Stud Thickness	-	1 5/8 x 3 5/8
		Category	-	Gypsum Board
		Material	-	Gypsum Regular 5/8"
		Thickness	-	-
		Category	-	Gypsum Board
		Material	-	Gypsum Regular 5/8"
		Thickness	-	-

Table 27: Sorted CIQS Level 3 Impact Estimator Assumptions

Level 3 Element	Assembly Group	Assembly Name	Specific Assumption
A11 Foundations	A11.1 Foundations	A11.1.1 Footing_F1	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(9’) x (31.5”/12)] / (19”/12) = 15.58 feet
		A11.1.2 Footing_F2	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(8.5’) x (27.6”/12)] / (19”/12) = 12.35 feet
		A11.1.3 Footing_F3	N/A
		A11.1.4 Footing_F4	N/A
		A11.1.5 Footing_F5	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(6.1’) x (21.7”/12)] / (19”/12) = 6.97 feet

		A11.1.6 Footing_F6	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(6.6’) x (23.6”/12)] / (19”/12) = 8.20 feet
		A11.1.7 Footing_F7	
		A11.1.8 Footing_F8	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(7.2’) x (25.6”/12)] / (19”/12) = 9.70 feet
		A11.1.9 Footing_F9	N/A
		A11.1.10 Footing_F10	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(6.4’) x (21.7”/12)] / (19”/12) = 7.31 feet
		A11.1.11 Footing_SF1	N/A
		A11.1.12 Footing_SF2	N/A

		A11.1.13 Footing_1400mm_LeftBasement	The area of this slab was measured and multiplied by the cited thickness to get the volume. Then the calculated volume was divided by the square root of the measured area and then divided again by 19" to get the width of the footing at 19". This was done using the following calculations; = [[(Measured Area) x (Cited Thickness)] / sqrt(Measured Area)] / (19”/12)] = [[(2,780.73' x (55.12"/12)] / (52.73)] / (19”/12) = 152.97 feet
		A11.1.14 Footing_700mm_SmallLeftBasement	The area of this slab was measured and multiplied by the cited thickness to get the volume. Then the calculated volume was divided by the square root of the measured area and then divided again by 19" to get the width of the footing at 19". This was done using the following calculations; = [[(Measured Area) x (Cited Thickness)] / sqrt(Measured Area)] / (19”/12)] = [[(339.02 ft2) x (27.56"/12)] / (18.41')] / (19”/12) = 26.71 feet
A21 Lowest Floor Construction	A21.1 Foundations	SOG - General	The Impact Estimator, SOG inputs are limited to being either a 4” or 8” thickness. Since the actual SOG thicknesses for the AERL building were not exactly 4” or 8” thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation.

		A21.1.1 SOG_125mm	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(10,952.63 x (4.9”/12))/(4”/12)] = 116.08 feet
		A21.1.3 SOG_150mm	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(4,805.08 ft2 x (5.9”/12))/(4”/12)] = 84.23 feet
		A21.1.2 SOG_200mm	The area of this slab had to be adjusted so that the thickness fit into the 8" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(2,628.03 x (7.9”/12))/(8”/12)] = 50.86 feet
A22 Upper Floor Construction	A22.1 Foundations	A22.1.1 Stairs_Concrete_TotalLength	The thickness of the stairs was estimated to be 14 inches based on the cross-section structural drawings

	A22.2 Columns and Beams	Columns - General	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. This being the case, in OnScreen, since no beams were present in the AERL building, concrete columns were accounted for on each floor, while each floor's area was measured. The number of beams supporting each floor was assigned an average bay and span size in order to cover the measured area, as seen assumption details below for each input. Since the live loading was not located within the provided building information, a live load of 75psf on all four floors and the basement level were assumed. The hollow structural steel (HSS) columns in the AERL building were modeled in the Extra Basic Materials, where their associated assumptions and calculations are documented.
		A22.2.1 Column_Concrete_Beam_N/A_Basement	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(1,568.91 ft2) / (6)] = 16.17 feet
		A22.2.2 Column_Concrete_Beam_N/A_GroundLevel	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(11,432.56 ft2) / (38)] = 17.35 feet

		A22.2.3 Column_Concrete_Beam_N/A_Level 2	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(13.161.53 ft2) / (41)] = 17.92 feet
		A22.2.4 Column_Concrete_Beam_N/A_Level 3	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(13.161.53 ft2) / (45)] = 17.10 feet
	A22.3 Floors	Floors - General	The Impact Estimator calculated the thickness of the material based on floor width, span, concrete strength, concrete flyash content and live load. The only assumptions that had to be made in this assembly group were setting the live load to 75psf, as well as setting the concrete strength 4,000 psi, instead of the specified 3,500psi. This was due to the IE's limitation to model only 3,000, 4,000 or 9,000psi concrete strengths.
		A22.3.1 Floor_ConcreteSuspendedSlab_200 mm	N/A
	A22.4 Extra Basic Materials	XBM - General	The Hollow Structural Steel (HSS) columns were accounted for using count conditions for the different types. Using their cross sectional sizing, provided in the Steel Column Schedule in structural drawing 316-07-003, in conjunction with their height and per foot weight, referenced from the Steel Tube Institute, allowed for the calculation of the amount of HSS in weight for the columns seen below.

		A22.4.1 XBM_Columns_HSS_(UpperFloor)	See bottom of chart for assumptions and calculations
A23 Roof Construction	A23.1 Columns and Beams	Columns - General	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. This being the case, in OnScreen, since no beams were present in the AERL building, concrete columns were accounted for on each floor, while each floor's area was measured. The number of beams supporting each floor were assigned an average bay and span size in order to cover the measured area, as seen assumption details below for each input. Since the live loading was not located within the provided building information, a live load of 75psf on all four floors and the basement level were assumed. The hollow structural steel (HSS) columns in the AERL building were modeled in the Extra Basic Materials, where their associated assumptions and calculations are documented.
		A23.1.1 Column_Concrete_Beam_N/A_Level 4	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(13.161.53 ft2) / (45)] = 17.10 feet
	A23.2 Roofs	Roof - General	The live load was assumed to be 75 psf and the concrete strength was set to 4,000psi instead of the specified 3,500psi.
		5.1.1 Roof_ConcreteSuspendedSlab_200 mm	Polyethylene was assumed to be 6mil.

		5.2.1 Roof_SteelJoist_Penthouse	Research showed that Dens-Deck Roof Board is essentially a fiberglass covered gypsum board that is also reinforced with glass fibers. This combination provides a product that is dimensionally stable, resistant to moisture and mold as well as fire. This material is not an option in the Impact Estimator, so a surrogate of 5/8" Moisture Resistant Gypsum was used in its place. Polyethylene was assumed to be 6mil.
	A23.3 Extra Basic Materials	XBM - General	The Hollow Structural Steel (HSS) columns were accounted for using count conditions for the different types. Using their cross sectional sizing, provided in the Steel Column Schedule in structural drawing 316-07-003, in conjunction with their height and per foot weight, referenced from the Steel Tube Institute, allowed for the calculation of the amount of HSS in weight for the columns seen below.
		A22.4.1 XBM_Columns_HSS_(RoofConstruction)	See bottom of chart for assumptions and calculations
A31 Walls Below Grade	A31.1 Walls (Cast-in-Place)	Walls - General	The length of the concrete cast-in-place walls needed adjusting to accommodate the wall thickness limitation in the Impact Estimator. It was assumed that interior steel stud walls were light gauge (25Ga) and exterior steel stud walls were heavy gauge (20Ga).
		A31.1.1 Wall_Cast-in-Place_150mm	This wall was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8”] = (27.18’) * [(5.91”)/8”] = 20.06 feet

		A31.1.2 Wall_Cast-in-Place_W1_200mm	This wall was reduced by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8"] = (331.87') * [(7.87")/8"] = 326.64 feet
		A31.1.3 Wall_Cast-in-Place_W2_200mm	This wall was reduced by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8"] = (394.48') * [(7.87")/8"] = 388.27 feet
		A31.1.4 Wall_Cast-in-Place_W1_400mm	N/A
A32 Walls Above Grade	A32.1 Walls (Cast-in-Place)	Walls - General	The length of the concrete cast-in-place walls needed adjusting to accommodate the wall thickness limitation in the Impact Estimator. It was assumed that interior steel stud walls were light gauge (25Ga) and exterior steel stud walls were heavy gauge (20Ga).
		A32.1.1 Wall_Cast-in-Place_300mm	N/A
		A32.1.2 Wall_Cast-In-Place_W3_200mm	This wall was reduced by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8"] = (394.48') * [(7.87")/8"] = 388.27 feet

	A32.2 Walls (Concrete Block Wall)	A32.2.1 Wall_ConcreteBlock_W4_200mm	Polyethylene was assumed to be 6mil because the this is a below ground wall.
		A32.2.2 Wall_ConcreteBlock_W4_200mm_ShortBrickAddIn_Length	Polyethylene was assumed to be 3mil because the this is an exterior wall.
	A32.3 Walls (Curtain Wall)	2.3.1 Wall_CurtainWall_AllGlazing	Aluminum Door with 80% glazing was the closest estimation to the observed doors in this wall.
		2.3.2 Wall_CurtainWall_MetalSpandrel	Aluminum Door with 80% glazing was the closest estimation to the observed doors in this wall.
	A32.4 Walls (Steel Stud)	2.4.3 Wall_SteelStud_W5	Research shows that Dens Glass Gold Sheathing is essentially a fiberglass covered gypsum board that is also reinforced with glass fibers. This combination provides a product that is dimensionally stable, resistant to moisture and mold as well as fire. This material is not an option in the Impact Estimator, so a surrogate of 5/8" Moisture Resistant Gypsum was used in its place. Windows were specified as having 'Warm Edge Technology' space bar, and Low Emissivity high transmittance coating. All these options were not available in the impact Estimator, so Low E Tin Glazing was assumed. Polyethylene was assumed to be 3mil because the this is an exterior wall.

		2.4.4 Wall_SteelStud_W5_SteelCladding-Add-in_Length	Research showed that Dens Glass Gold Sheathing is essentially a fiberglass covered gypsum board that is also reinforced with glass fibers. This combination provides a product that is dimensionally stable, resistant to moisture and mold as well as fire. This material is not an option in the Impact Estimator, so a surrogate of 5/8" Moisture Resistant Gypsum was used in its place. Polyethylene was assumed to be 3mil because the this is an exterior wall.
B11 Partitions	B11.1 Walls (Cast-in-Place)	Walls - General	The length of the concrete cast-in-place walls needed adjusting to accommodate the wall thickness limitation in the Impact Estimator. It was assumed that interior steel stud walls were light gauge (25Ga) and exterior steel stud walls were heavy gauge (20Ga).
		B11.1.1 Wall_Cast-in-Place_NoEnv_200mm	N/A
		B11.1.2 Wall_Cast-in-Place_200mm_P1	N/A
		B11.1.3 Wall_Cast-in-Place_200mm_P3	This wall's measured length was reduced by a factor of 2 order to fit the 1 5/8" x 3 5/8" stud thickness limitation of the Impact Estimator since the studs were specified as 1 5/8" x 1 13/16" . Because the length of the wall was halved the amount of gypsum they were covered with was halved as well. To compensate for this both side were covered with gypsum.
		B11.1.4 Wall_Cast-in-Place_250mm	N/A
		B11.1.5 Wall_Cast-in-Place_400mm_P3	This wall's measured length was reduced by a factor of 2 order to fit the 1 5/8" x 3 5/8" stud thickness limitation of the Impact Estimator since the studs were specified as 1 5/8" x 1 13/16" . Because the length of the wall was halved the amount of gypsum they were covered with was halved as well. To compensate for this both side were covered with gypsum.
		B11.2.1 Wall_ConcreteBlock_P2_Partition	Steel Interior Door with 50% glazing was the closest estimation to the observed doors in this wall.

	B11.3 Walls (Curtain Wall)	B11.3.1 Wall_CurtainWall_TypeSF1	Steel Interior Door with 50% glazing was the closest estimation to the observed doors in this wall. There was no insulation in this curtain wall since it is indoors, however, the Impact Estimator does not accept an input of zero.
	B11.4 Walls (Steel Stud)	B11.4.1 Wall_SteelStud_P3_Partition	This wall's measured length was reduced by a factor of 2 order to fit the 1 5/8" x 3 5/8" stud thickness limitation of the Impact Estimator since the studs were specified as 1 5/8" x 1 13/16" . This was done using the following equation; = (Measured Length) / 2 = (498.24’) / 2 = 249.12 feet Because the length of the wall was halved the amount of gypsum they were covered with was halved as well. To compensate for this both side were covered with gypsum.
		B11.4.2 Wall_SteelStud_P4_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate. Steel Interior Doors with 50% glazing were selected as the closest representation to the observed door type in this wall.
		B11.4.3 Wall_SteelStud_P5_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate. Steel Interior Doors with 50% glazing were selected as the closest representation to the observed door type in this wall.
		B11.4.4 Wall_SteelStud_P6_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate. Steel Interior Doors with 50% glazing were selected as the closest representation to the observed door type in this wall.

		B11.4.5 Wall_SteelStud_P7_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate. Steel Interior Doors with 50% glazing were selected as the closest representation to the observed door type in this wall.
		B11.4.6 Wall_SteelStud_P8_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate. Steel Interior Doors with 50% glazing were selected as the closest representation to the observed door type in this wall.
		B11.4.7 Wall_SteelStud_P9_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate. Steel Interior Doors with 50% glazing were selected as the closest representation to the observed door type in this wall.
		B11.4.8 Wall_SteelStud_P10_Partition	Acoustic Batt insulation was not available in the Impact Estimator so Fiberglass Batt was selected as the closest surrogate
		B11.4.9 Wall_SteelStud_Type29	Since this was an interior wall, no sheathing was considered. The gypsum on both sides was assumed to be of the same specifications as the other walls (ie.5/8" Regular Gypsum).

Table 28: IE Inputs Document – Calculation for Upper Floor Construction Steel

Upper Floor Construction					
Description	Count	Section	kg/m	mm2	kg
XBM_Columns_HSS_102x76x9.5_Level3	2	HSS 102x76x9.5	21.9	2570	160
XBM_Columns_HSS_76x76x6.4_Level3	2	HSS 76x76x6.4	13.1	1310	96
XBM_Columns_HSS_SC1_Level3	11	HSS 89x89x8	18.9	2410	760
XBM Columns HSS SC2 Level2	20	HSS 89x89x9.5	21.9	2790	1602
XBM_Columns_HSS_SC2_Level3	11	HSS 89x89x9.5	21.9	2790	881
XBM_Columns_HSS_SC3_Level2	9	HSS127x76x8	22.1	2820	728
XBM_Columns_HSS_SC3_Level3	11	HSS127x76x8	22.1	2820	889
XBM Columns HSS SC4 GroundLevel	5	HSS 102x102.9.5	25.7	3280	470
XBM_Columns_HSS_SC5_Level2	2	HSS 152x102x6.4	23.2	2960	170
XBM_Columns_HSS_SC5_Level3	4	HSS 152x102x6.4	23.2	2960	339

Table 29: IE Inputs Document – Calculation for Roof Construction Steel

Roof Construction					
Description	Count	Section	kg/m	mm2	kg
XBM_Columns_HSS_102x76x9.5_Level4	2	HSS 102x76x9.5	21.9	2570	160
XBM_Columns_HSS_102x76x9.5_Level5	2	HSS 102x76x9.5	21.9	2570	160
XBM_Columns_HSS_76x76x6.4_Level4	2	HSS 76x76x6.4	13.1	1310	96
XBM Columns HSS 76x76x6.4 Level5	2	HSS 76x76x6.4	13.1	1310	96
XBM_Columns_HSS_SC1_Level4	33	HSS 89x89x8	18.9	2410	2281
XBM_Columns_HSS_SC5_Level4	4	HSS 152x102x6.4	23.2	2960	339
XBM_Columns_HSS_SC5_Roof	49	HSS 152x102x6.4	23.2	2960	4158