# Life Cycle Assessment of The Civil and Mechanical Engineering Building

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# 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

# Life Cycle Assessment of The Civil and Mechanical Engineering Building

## CIVL 498C: Life Cycle Assessment
## University of British Columbia

Due: November 18, 2013

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# 1.0 Executive Summary

This report contains an in-depth Life Cycle Analysis of the Civil and Mechanical Engineering (CEME) Building at the University of British Columbia in Vancouver, British Columbia. The life cycle analysis scope includes the envelope and structure of CEME from cradle to gate, that is, from the building's product manufacturing to end of construction stage.

The methods used to achieve a detailed analysis included contributions from two authors. The first author included a thorough on screen takeoff of CEME's level three elements including foundations, walls/floors above and below grade, roof structure and interior partition walls. The second contributor then assessed the quality of the initial study and made improvements to the accuracy of that study. An impact assessment was then performed on each element to determine its contribution by impact category to overall impacts for CEME as a whole. The results of the impact assessment were then compared to 22 other institutional buildings at UBC to determine how CEME equated.

It was determined that CEME's had less of an environmental impact than the majority of other buildings at UBC as it's impact category values were lower than the benchmark's value. Furthermore, CEME's level three element "A23 Upper Floor Construction" contributed the most in all seven impact categories included in the Athena Impact Estimator. Finally, it was discovered that the product stage had a larger impact that the construction stage for all level three elements, it was approximately 80-90% larger in all cases.

This report also includes interpretations of the results such as recommendations for LCA use to be put in practice and an author's reflection of the project and CIVL 498C as a whole.

# 2.0 General Information on the Assessment

## 1.1 Purpose of the assessment

The purpose of this assessment is to evaluate the environmental performance of the Civil and Mechanical Engineering Building (CEME) throughout the life cycle of the building. Its intended use is to be used as a tool to evaluate what the main sources of environmental impact in an institutional building's design are and to investigate how to reduce a building's impact. Furthermore this study can be used as a materials inventory for CEME. Policy makers can also use the study to help influence the decisions they make when establishing new sustainability guidelines for new construction to be performed at UBC.

The study is intended for comparative assertions as it compares the environmental performance of the CEME building next to 22 other academic buildings located on campus at UBC. The function the buildings have in common is square footage and their environmental impacts will be compared to each individual building, as well as the benchmark value.

The intended audience for this study is the University of British Columbia, other academic institutions and industry professionals. Industry professionals can include institutional building owners, engineers, architects and building developers who are interested in learning about how to perform an Life Cycle Assessment on new construction or learn more about the Life Cycle Assessment process for buildings in general. It can further be used by any individuals involved in the developmental planning department or policy making at UBC as a reference tool.

In terms of comparing CEME to other buildings at UBC, the level of detailed required for each building will vary according to the individual performing each separate LCA study. Some individuals will have more detailed and accurate models due to the level of information available to them, while others will not as the are working with older drawings. Because this report will be for UBC planning purposes only, the benchmark value will contain a variety of very detailed reports and undetailed reports. As the average value is taken, the level of detail required should be as detailed as the user can make it with the information they have available. This model of CEME has been improved from the previous LCA study, and is as thorough as it can be with the information that was available.

## 1.2 Identification of building

The Civil and Mechanical Engineering building is approximately 111, 159 square feet and is divided into five sections, Areas 1, 2, 3, 4, 5. Table 1 below describes the purpose of each of the five sections. The building itself cost $6.7 Million dollars when it was constructed and was completed within two years from 1974 to 1976. The net present value of the construction is $16, 720, 000. The calculations for this number can be found on the attached excel spreadsheet. The architect and engineers who conducted the design process was Philips, Barnett, Architects and Engineers.

| Area | Building Intended Use |
|---|---|
| 1 | Mechanical Engineering Laboratory and Shops. |
| 2 | Mechanical Engineering Laboratory and Offices. |
| 3 | Common Facilities |
| 4 | Civil Engineering Laboratory and Offices |
| 5 | Pollution Control and Surveying |

**Table 1 - Description of CEME's 5 Areas**

The building is located at 2002 – 6250 Applied Science Lane, Vancouver, BC, Canada, V6T 1Z4. The primary use of the CEME is as an institutional learning facility for civil and mechanical engineering students, office space for civil and mechanical engineering professors as well as an administrative building for the two faculties respectively. There are nine classrooms in the building, twenty-nine laboratories, seventy-two offices and eight large multipurpose study spaces/workspaces. There are four different types of laboratories in the building: soil, environmental, mechanical and computer. The five sections can be divided into 4 categories, basement, main floor, upper floor and penthouses. The penthouses are used mainly for mechanical purposes.

CEME's structure can be described as concrete columns supporting concrete beams, which support a precast T-Beam joist floor. The exterior walls are made of predominantly pre-cast concrete panels and concrete block walls. The interior walls are made up of a variety of concrete block, wood stud and steel stud walls. The window glazing is assumed to be standard with aluminum frames and insulated steel stud wall panel with asbestos. 1" insulation and asphalt roofing for a precast concrete t-beam is assumed for the roof structure.

## 1.3 Other Assessment Information

Table 2 listed below provides a summary of assessment information.

| | |
|---|---|
| **Client for Assessment** | Completed as coursework in Civil Engineering technical elective course at the University of British Columbia. |
| **Name and qualification of the assessor** | *First Author*<br>Cayley Van Hemmen – Civil Engineering Student 2013<br>*Second Author*<br>Tyler Algeo – Civil Environmental Engineering Student 2011 |
| **Impact Assessment Method** | *Impact Assessment Method:*<br>Mid Point Impact Estimation Method TRACI, Version 2012 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts)<br>*Impact Estimator:*<br>Athena Impact Estimator Version 4.2.0208 |
| **Point of Assessment** | 37 years. |
| **Period of Validity** | 5 years. |
| **Date of Assessment** | Completed in December 2013. |
| **Verifier** | Student work, study not verified. |

**Table 2 - Summary of CEME's Assessment Information**

# 3.0 General Information On The Object of Assessment

## 2.1 Functional Equivalent

ISO14044 defines a function unit to be "A performance characteristic of the product system being studied that will be used as a reference unit to normalize the result of the study." Essentially it is a unit that defines and quantifies what is being produced by the product system as a whole in respect to inputs and outputs in the Life Cycle Assessment Study. It defines the function one measures the performance of a system over. The most common functional unit to use to incorporate an entire building is meters squared of floor area, which was used in this assessment. Functional units are important for this intended application of CEME's LCA as LCA is commonly used as a decision-making support tool in the design process. The function unit is very important when comparing one building to another building, as it is the normalizing factor between them when comparing impacts. Therefore, if a policy maker were deciding on how large to construct a building, they would consider the function unit of CEME's building to its environmental impacts. The following table below concisely describes CEME's functional equivalent.

| **Aspect of Object of Assessment** | **Description** |
|---|---|
| Building Type | CEME is an institutional building containing:<br>- Office Spaces<br>- Classroom Spaces<br>- Multipurpose Rooms / Study / Workspaces<br>- Soil and Environmental Laboratories<br>- Computer Laboratories<br>- Mechanical Laboratories<br>- Penthouses |
| Technical and Functional requirements | Not a LEED Building therefore do not need to meet and special regulatory requirements. However, building was required to meet the National Building Code and the BC Building Code[1], which was established in 1973. |

[1] Author Unknown - Office of Housing and Construction Standards (2013). *History of British Columbia Regulations.* Retrieved from http://www.housing.gov.bc.ca/pub/regHistory.pdf

| | |
|---|---|
| | The client specifically requested the following building requirements that are unique to CEME:<br>- A "Civil Engineering Design Studio" within the building to give students the opportunity to work together and collaborate in groups to mirror the industry working environment.[2]<br>- Environmental/Soil/Mechanical Laboratories to teach various subjects such as solid waste management, geotechnical and environmental engineering principles.[3] |
| Pattern of use | *Design Occupancy*<br>The design drawings do no specify the design number of building occupants. However, as per UBC classroom services, the current capacity for rooms 102, 1202, 1204, 1206, 1210, 1212, 1215 is approximately 303 occupants.[4] This number does not include the administrative offices or laboratories. A more accurate representation would be around 600 but this is approximate.<br>*Pattern of Use*<br>The building was designed for maximum occupancy during weekdays between the building hours of 07:00 – 23:00. |
| Required service life | The building service life was not specified on the drawings and the information is not listed on the UBC classroom services website. Therefore as per www.technicalguidelines.ubc.ca it states all key building |

[2] University of British Columbia (2013). *Civil Engineering Design Studio For Undergraduate Students.* Retrieved from http://www.civil.ubc.ca/about/facilities/designstudio.php

[3] University of British Columbia (2013). *Environmental Laboratory.* Retrieved from http://www.civil.ubc.ca/home/env_lab/

[4] University of British Columbia (2013). *Buildings and Classrooms, Civil and Mechanical Engineering.* Retrieved from http://www.students.ubc.ca/classroomservices/buildings-and-classrooms/?code=CEME

| | |
|---|---|
| | envelopes should have a service life of 100 years unless it is a temporary structure. In this case, it is not.[5] |

Table 3 - Functional Equivalent With Respect To CEME

## 2.2 Reference Study Period

The required service life for CEME is assumed to be 100 years, as it is not explicitly stated on the drawings. 100 years is a typical value for institutional buildings. For our LCA model however, it is assumed the service life of CEME to be set to 1 year, as the study is a cradle to gate assessment. This is because the life Cycle Inventory Assessment results focus on only the manufacturing/transportation/installation of materials in the building's construction. This will allow the maintenance and operational energy, end-of-life states and supplementary information beyond the building life cycle to be excluded from the buildings life cycle assessment scope. The replacement rates for building materials were not included in scope as

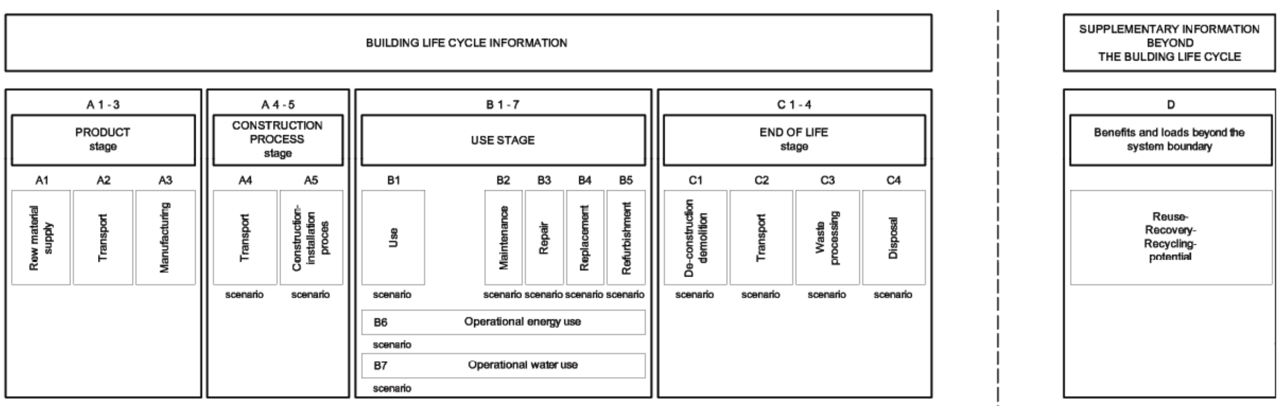


**Figure 6 — Display of modular information for the different stages of the building assessment**

Figure 1 - Display of Building Cycle Information

they were not part of CIVL 498C. Those three excluded states are shown below as categories B, C, and D.

## 2.3 Object of Assessment Scope

The scope of this study is assumed to be the entire product system of CEME including its structure, envelope and operational energy. This includes all structures from the foundations to

[5] University of British Columbia (2013). *Performance Objectives.* Retrieved from http://www.technicalguidelines.ubc.ca/technical/performance_obj.html

the roofing. There are no deviations from the scope that are excluded. In order to ensure the cradle-to-gate scope is accurate, the LCA encompasses associated transportation affects, the manufacturing of the materials and the construction of the overall structure/envelope.

It was decided to use CIQS (Canadian Institute of Quantity Surveryors) as it is a Canadian standard format. Each element is a major component that fulfills the same function in every building. The system divides the elements into 4 categories: Level 1 ‘Major Elements’, Level 2 ‘Group Elements’, Level 3 ‘Elements’, and Level 4 ‘Sub-Elements.’ [6] For this project, only Level 1 elements ‘Shell’ and ‘Interior Materials’ are included. The elements chosen can be shown in the

| Level 1 | Level 2 | Level 3 |
|---|---|---|
| A SHELL | A1 SUBSTRUCTURE | A11 Foundations |
| | A2 STRUCTURE | A21 Lowest Floor Construction |
| | | A22 Upper Floor Construction |
| | | A23 Roof Construction |
| | A3 EXTERIOR ENCLOSURE | A31 Walls Below Grade |
| | | A32 Walls Above Grade |
| B INTERIORS | B1 PARTITIONS & DOORS | B11 Partitions |

**Figure 2 - CIQS Elements Division For CEME**

Figure 2. These elements were specifically chosen as they only include the shell and envelope of the building. The remaining interior Level 2 elements (Finishes, fittings and equipment) were excluded accordingly. Furthermore, The Level 1 elements, ‘C - Services’, ‘D - Site and Ancillary Work’ and ‘Z - General Requirement’ either fit into the Operation and Maintenance of the building which is not part of the scope of this cradle to gate assessment, or were not applicable. As stated earlier, CEME contains two floors, the main floor on grade as well as an upper second floor. The building also includes a basement and a couple penthouses. All building foundations support this structure. The table below describes in further detail what in contained in each CIQS section for the scope of this project.

[6] Sianchuk, R. (2013). *CIQS Elemental Format.* Retrieved from http://civl498c.wikispaces.com/file/view/Final%20Project_CIQS%20Elements_071013.pdf/457652562/Final%20Project_CIQS%20Elements_071013.pdf

| CIVL 498C Level 3 Elements | Description | Quantity (Amount) | Units |
|---|---|---|---|
| A11 Foundations | - All column footings (F.1-31, f.Str, f.ramp)<br>- All strip footings (f.A, f.B, f.B/C/E/F, f.B/C/E/F-2, f.C, f.D, f.G, f.J, f.JJ, f.JJJ) | 6555.4 | $m^2$ |
| A21 Lowest Floor Construction | - Concrete Slab On Grade (First Floor Construction In CEME) | 6555.4 | $m^2$ |
| A22 Upper Floor Construction | - Concrete Slab (Second Floor CEME)<br>- lConcrete Precast Double T (Second Floor CEME)<br>- Columns and beams supporting the first and second floors | 7006.0 | $m^2$ |
| A23 Roof Construction | - Open Web Steel Joists (Roof Structure)<br>- Concrete Precast Double T (Roof Structure)<br>- Columns and beams supporting the roof. | 4286.0 | $m^2$ |
| A31 Walls Below Grade | - All basement walls were determined to be only exterior. | 447.1 | $m^2$ |
| A32 Walls Above Grade | - All remaining exterior walls (excluding basement walls)<br>- Includes extra basic materials in the window frames surrounding the building. | 6055.0 | $m^2$ |
| B11 Partitions | - All interior walls (There were no basement interior walls) | 9363.3 | $m^2$ |

**Table 4 - CEME's Building Definition**

# 3.0 Statement of Boundaries and Scenarios Used In This Assessment

## 3.1 System Boundary

The system boundary includes the unit processes, geographical area and time period we are studying. For the assessment of CEME, the life cycle modules included are the A1-3 Product Stage and the A4-5 Construction Process Stage. The table below Illustrates a general overview of what upstream and downstream processes support these modules over the reference study period.

| | | UPSTREAM PROCESSES | DOWNSTREAM PROCESSES |
|---|---|---|---|
| A1-3<br>Product Stage | A1<br>Raw Material Supply | - **At this point the material enters the system boundary.**<br>- Searching For Raw Materials<br>- Investigative work for resources. | - Disposal of wastes that result from extraction of raw materials. |
| | A2<br>Transport | - Preparing materials for delivery to manufacture. (EX. Wrapping in Styrofoam for protection etc.) | - Receiving materials and processing them. (EX. Removing packaging) |
| | A3<br>Manufacturing | - Preparing materials for manufacturing (Ex. Cutting lumber etc.) | - Disposal of excess material wastes due to manufacturing process. |
| A4-5<br>Construction Process Stage | A4<br>Transport | - Preparing materials for delivery. | - Receiving materials on the construction site. |
| | A5<br>Construction Installation Process | - Moving materials when ready for installation.<br>- Preparation work before installation – EX. Installing formwork for concrete slab. | - Disposal of construction waste and excess materials.<br>- **At this point the material leave the system boundary.** |

Table 5 - CEME Upstream and Downstream Processes

## 3.2 Product Stage

The process information included for the product phase includes extraction of raw materials, manufacturing of products, generation of the energy input, production of ancillary materials, packaging, transportation up to production gate and construction site, collection and transport of waste, and waste management.

### 3.2.1 Extraction of Raw Material Production

LCI data collection includes impacts associated with the extraction of raw materials. It includes all impacts such as emissions to air, water and land from the extraction phases. For example, all activities that are associated with mining a resource will be encompassed, such as the technique of separating valuable ore from waste. Transportation of the raw material extracted to a manufacturing plant is also included in this phase. It is important to note that some land impact measures cannot be addressed, such as loss of biodiversity, because of its complexity and the fact it is already tracked by other regulatory bodies.[7]

### 3.2.2 Manufacturing of products

Athena states the manufacturing stage begins with the delivery of resources to the manufacturing plant and is finished when the product is ready to be transported to the next stage. Let it be aware that the Athena LCA Impact Estimator combines the resources extraction and manufacturing stage for simplicity when reporting results.

### 3.2.3 Generation Of Energy Input

The method of refining is a good example that illustrates effect of the amount of generation of energy input depending on the material in the product stage. For example, steel made in integrated plants requires more energy to make than if steel was made in mini-mills from scrap feedstock energy.[8]

### 3.2.4 Production of Ancillary Materials

Production of ancillary materials can also be included in the life cycle of a product depending on the system boundary. For example, in the production of corrugated packaging, containerboard

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[7] Athena Sustainable Building Materials Institute (2013). *Technical Details.* Retrieved from http://www.athenasmi.org/resources/about-lca/technical-details/

[8] Markus Engineering Services, Athena Sustainable Building Materials Institute (2002). *Cradle to Gate Life Cycle Inventory: Canadian and US Steel Production By MIL Type.* Retrieved from http://www.athenasmi.org/wp-content/uploads/2011/10/1_Steel_Production.pdf

mills ancillary inputs such as wood and paper pulp, pulping and bleaching chemicals and wood fiber production are included.[9]

### 3.2.5 Packaging

Packaging is also included in various LCA modules depending on the material being produced. For example, particleboard is packaged and stacked in a warehouse before it is shipped to site. The material used to package it and the energy required to package it is all included in the production stages. [10]

### 3.2.6 Transportation Up To Production Gate

Transportation to the production site usually is one of the larger contributors to the production module stage. As per the exercise in CIVL 498C, it was evident that by speeding up the transportation process the material would be delivered much faster and more likely to use less waste. Transportation is also included in the production module, but only encompasses the emissions that come from the transportation from the manufacturing plant to the construction site.

### 3.2.7 Collection and Transport of Waste and Waste Management Processes.

Collection, transport and disposal of waste is usually included in the manufacturing models. For example, an LCA of particleboard includes all processes involved in the transportation of on-site waste at the production plant.[10] Furthermore, the impacts associated with waste disposal are included and are outlined in "Section 3.3.4 – Waste Management Processes In Construction Stage"

## 3.3 Construction Stage

The process information included for the construction phase accounts for the following four categories: transportation from manufacturing stage, storage of products, installation and waste management.

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[9] PE-Americas, Five Winds International, Corrugated Packaging Alliance (2010). *Corrugated Packaging Life Cycle Assessment Summary Report.* Retrieved from http://www.corrugated.org/upload/LCA%20Summary%20Report%20FINAL%203-24-10.pdf

[10] Athena Sustainable Materials Institute (2013). *A Cradle-to-Gate Life Cycle Assessment of Canadian Particleboard – 2013 Update.* Retrieved from http://www.athenasmi.org/wp-content/uploads/2013/10/CtoG-LCA-of-Canadian-PB-Update.pdf

### 3.3.1 Transportation From The Manufacturing Gate to the Construction Site

The effect of transportation of materials from the manufacturing gate to the construction site will only have a large impact if the material being delivered is widely available. For example, the transportation impact will be very low for concrete as concrete is produced in a large number of locations. However, specialty items that are only produced in one city will have a large transportation effect as it will have to specially be either shipped in by train or by airplane depending on the construction sites location.[11] All of the transportation distances are based on regional surveys and therefore will account for differences in location.[12]

### 3.3.2 Storage of products, including the provision of heating, cooling, humidity etc.

Depending on where the construction is taking place, heating/cooling might be required for materials on site. Athena takes this into account as best it can, by accounting for the proportion of energy that will be needed for storage of materials. In the case of the concrete wall, if a slab-on grade were to be construction in a cold climate like Fort McMurray in the winter season, heating would be required during the casting and curing process. Athena accounts for the difficulties whether the wall will be constructed in cold climates below zero, so they factor a proportion of energy needed to heat concrete equal to the time of the year in that location where the temperature drops below zero. [7]

### 3.3.3 Installation of the product into the building (including ancillary materials) and on site transformation of construction products.

The Athena impact estimator software also take into account all of the energy used to build and erect the element in the construction phase. For example, it will include all energy associated with building a cast-in-place concrete wall, such as assembling the formwork and rebar, and pouring the concrete. The database will include all transportation of materials, such as the energy it takes for on-site equipment to move rebar on site using either forklifts or cranes. [7]

### 3.3.4 Waste management processes on the construction site and waste handling until final disposal.

The Athena Impact Estimator Software includes waste management in construction. Continuing from the early example of a concrete wall being construction, Athena takes into account that

[11] Athena Sustainable Materials Institute (2013). *Frequently Asked Questions – Impat Estimator For Buildings.* Retrieved from http://calculatelca.com/faqs/#ie4b_project_data

[12] Athena Sustainable Materials Institute (2013). *Athena Impact Estimator V 4.2 Software and Database Overview.* Retrieved from http://calculatelca.com/wp-content/uploads/2011/11/ImpactEstimatorSoftwareAndDatabaseOverview.pdf (Page 19)

there will be approximately 5% of concrete lost due to spillage/dumping and also accounts for the approximate reuse of formwork until it has degraded to the point of waste. Assumptions of overall waste of materials are made, in the case of the concrete wall; it would be an overall 10% loss. [7] The process includes all transportation energy factors for disposal as well.

# 4.0 Environmental Data

## 4.1 Data Sources

### 4.1.1 LCI Data Collection Overview

Typically LCI databases are developed by using input and output data on a material to create flow models that illustrate the activities of a product in its supply chain. Data is collected using survey questionnaires or representative industry data that include questions about a products inputs and outputs of the product that accounts for 99% of energy flows. The data is collected from a specific group of producers, typically middle of the line companies that are not the best or worst in their field, in order to get a more accurate representative model. Regional differences are accounted for in these databases.[13]

### 4.1.2 Athena LCI Database

Currently, Athena maintains their LCI database. They are an independent third-party separate from the NREL and build their database without any trade or government sources. Athena experts with background in LCA connect with the construction industry to conduct life cycle inventories on various products using survey questionnaires. Athena is unique in that they try to include all materials used in the construction of an item. For example, Athena collects information on not only a gypsum wallboard, but also information on the specific type of mud used for taping to finish the wallboard. Their LCI databases also include information on construction/demolition processes, transportation and energy use, as well as standard information on building materials.[14]

### 4.1.3 US LCI Database

The US LCI Database concept was developed on May 1, 2001 from a conference given by Ford Motors.[15] It gained quick support and was created by an advisory group of 45 individuals who represented the following industries: Manufacturing, Government, Non-Government and LCA

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[13] Trusty. W, Athena Sustainable Materials Institute (2010). *An Overview of Life Cycle Assessments: Part One of Three* Retrieved from "Online Bulding Safety Journal" at http://www.athenasmi.org/wp-content/uploads/2012/05/BSJ_overview_life_cycle_assessment.pdf

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

[15] National Renewable Energy Laboratory (2013). *U.S. Life Cycle Inventory Databases.* Retrieved from http://www.nrel.gov/lci/about.html

Experts. This advisory board came together to create a 20-page document outlining the development guidelines for the LCI database, including their goal of creating "publically available LCI data modules for commonly used materials, products and processes." In 2009, the NREL outlined a detailed plan to continue to improve the quality of the LCI Database by identifying the critical areas that needed improvement and created goals to improve that area. These goals are outlined in the figure below from the NERL website:

| Project Management | Data Management | LCI Data | Communications |
|---|---|---|---|
| • Complete annual operating plan.<br>• Establish advisory boards.<br>• Develop a business plan.<br>• Partner with national and international efforts. | • Define a data quality protocol.<br>• Revise data formats and protocols.<br>• Complete database updates. | • Fill data gaps.<br>• Expand the database.<br>• Maintain current data. | • Identify user needs.<br>• Develop a communications plan.<br>• Update Web site and project documents. |

**Figure 3 - US LCI Database Action Plan**

Currently, the US LCI Database is run and managed by a two-man project management team from the National Renewable Energy Laboratory, Michael Deru and Alberta Carpenter, both of whom have professional backgrounds in life cycle analysis.[16]

## 4.2 Data Adjustments and Substitutions

The largest issue presented in this model was that it had no material specifications listed for any of the concrete/rebar used. These inconsistencies are laid out in the Annex D – Inputs and Assumptions section of the report. As it was assumed that the concrete was 25 MPa, but the impact estimator only allows the user to select either 20 MPa or 30 MPa, material substitutions were used to illustrate the difference in impacts in entering 25 MPa of concrete into the model instead of 20 Mpa. The process I used is described in the following 7 steps:

**Step 1:** Determine the impacts for the singular wall that is assumed to be 25 Mpa. This was done by showing the reports for the wall on the Athena Impact Estimator.

[16] National Renewable Energy Laboratory (2013) *Project Management Team.* Retrieved from http://www.nrel.gov/lci/project_team.html

| Summary Measures | PRODUCT | | | CONSTRUCTION PROCESS | | | USE | | | | END OF LIFE | | | TOTAL EFFECTS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturing | Transport | Total | Construction-installation Process | Transport | Total | Replacement Manufacturing | Replacement Transport | Operational Energy Use Annual | Total | Material | Transport | Total | Non-Transport | Transport | Operational Energy Use | Total |
| Fossil Fuel Consumption (MJ) | 26224.89093 | 936.0176704 | **27160.9086** | 3906.75483 | 1812.71658 | **5719.471418** | 0 | 0 | 0 | **0** | 2038.5357 | 689.962183 | **2728.49788** | 32170.1815 | 3438.69644 | 0 | **35608.8779** |
| Global Warming Potential (kg CO2 eq) | 2350.308751 | 67.84892541 | **2418.157676** | 301.757771 | 139.245807 | **441.0035782** | 0 | 0 | 0 | **0** | 137.025688 | 53.0753504 | **190.1010384** | 2789.09221 | 260.170083 | 0 | **3049.262293** |
| Acidification Potential (kg SO2 eq) | 12.34473961 | 0.328572734 | **12.67331235** | 2.40562785 | 0.64407239 | **3.049700239** | 0 | 0 | 0 | **0** | 1.83843593 | 0.24522314 | **2.083659067** | 16.5888034 | 1.21786826 | 0 | **17.80667165** |
| HH Particulate (kg PM2.5 eq) | 4.642286683 | 0.010014124 | **4.652300807** | 0.24497403 | 0.01996085 | **0.264934886** | 0 | 0 | 0 | **0** | 0.04812862 | 0.00760299 | **0.055731617** | 4.93538934 | 0.03757797 | 0 | **4.97296731** |
| Eutrophication Potential (kg N eq) | 0.910352824 | 0.023585697 | **0.933938521** | 0.14271611 | 0.04648434 | **0.18920045** | 0 | 0 | 0 | **0** | 0.12247374 | 0.01770075 | **0.140174496** | 1.17554267 | 0.0877708 | 0 | **1.263313467** |
| Ozone Depletion Potential (kg CFC-11 eq) | 1.59969E-05 | 2.71222E-09 | **1.59996E-05** | 8.129E-07 | 5.5502E-09 | **8.18455E-07** | 0 | 0 | 0 | **0** | 5.9871E-09 | 2.1154E-09 | **8.10249E-09** | 1.6816E-05 | 1.0378E-08 | 0 | **1.68262E-05** |
| Smog Potential (kg O3 eq) | 131.7044974 | 11.62070249 | **143.3251999** | 73.4151703 | 22.7745485 | **96.18971884** | 0 | 0 | 0 | **0** | 65.2118287 | 8.67110248 | **73.88293122** | 270.331496 | 43.0663535 | 0 | **313.3978499** |

**Step 2:** Determine the impacts for only the concrete material in the same volume as the original wall minus the concrete lost to waste (5%). Use the impact estimator to see the summary of impacts.

| Summary Measures | PRODUCT | | | CONSTRUCTION PROCESS | | | USE | | | | END OF LIFE | | | TOTAL EFFECTS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturing | Transport | Total | Construction-installation Process | Transport | Total | Replacement Manufacturing | Replacement Transport | Operational Energy Use Annual | Total | Material | Transport | Total | Non-Transport | Transport | Operational Energy Use | Total |
| Fossil Fuel Consumption (MJ) | 9266.397223 | 636.8488093 | **9903.246032** | 1712.67095 | 1024.54211 | **2737.213066** | 0 | 0 | 0 | **0** | 1557.25044 | 491.7397 | **2048.99014** | 12536.3186 | 2153.13062 | 0 | **14689.44924** |
| Global Warming Potential (kg CO2 eq) | 1256.678801 | 45.98174376 | **1302.660545** | 146.812451 | 78.6626657 | **225.475117** | 0 | 0 | 0 | **0** | 104.674798 | 37.8270831 | **142.5018815** | 1508.16605 | 162.471493 | 0 | **1670.637543** |
| Acidification Potential (kg SO2 eq) | 5.83966041 | 0.223243832 | **6.062904242** | 1.41869958 | 0.36398577 | **1.782685355** | 0 | 0 | 0 | **0** | 1.40439295 | 0.17477183 | **1.579164778** | 8.66275294 | 0.76200144 | 0 | **9.424754375** |
| HH Particulate (kg PM2.5 eq) | 3.218038794 | 0.006797932 | **3.224836727** | 0.19039838 | 0.01127895 | **0.201677332** | 0 | 0 | 0 | **0** | 0.03676576 | 0.00541869 | **0.042184456** | 3.44520294 | 0.02349558 | 0 | **3.468698515** |
| Eutrophication Potential (kg N eq) | 0.138761304 | 0.016020375 | **0.154781679** | 0.08199817 | 0.02626859 | **0.108266764** | 0 | 0 | 0 | **0** | 0.09355847 | 0.01261542 | **0.106173895** | 0.31431795 | 0.05490439 | 0 | **0.369222338** |
| Ozone Depletion Potential (kg CFC-11 eq) | 1.23248E-05 | 1.83863E-09 | **1.23266E-05** | 6.1991E-07 | 3.1355E-09 | **6.23043E-07** | 0 | 0 | 0 | **0** | 4.5736E-09 | 1.5077E-09 | **6.08123E-09** | 1.2949E-05 | 6.4818E-09 | 0 | **1.29557E-05** |
| Smog Potential (kg O3 eq) | 70.39484421 | 7.895726357 | **78.29057056** | 43.4859148 | 12.8706462 | **56.35656097** | 0 | 0 | 0 | **0** | 49.8157325 | 6.17994063 | **55.99567316** | 163.696492 | 26.9463132 | 0 | **190.6428047** |

**Step 3:** Take original wall impacts and minus the "extra wall materials" impacts. This will give you the impacts to build the wall (includes the formwork, rebar etc.) but minus the concrete.

| Summary Measures | PRODUCT | | | CONSTRUCTION PROCESS | | | USE | | | | END OF LIFE | | | TOTAL EFFECTS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Manufacturing | Transport | Total | Construction-installation Process | Transport | Total | Replacement Manufacturing | Replacement Transport | Operational Energy Use Annual | Total | Material | Transport | Total | Non-Transport | Transport | Operational Energy Use | Total |
| Fossil Fuel Consumption (MJ) | 16958.49371 | 936.0176704 | **27160.9086** | 3906.75483 | 1812.71658 | **5719.471418** | 0 | 0 | 0 | **0** | 2038.5357 | 689.962183 | **2728.49788** | 32170.1815 | 3438.69644 | 0 | **35608.8779** |
| Global Warming Potential (kg CO2 eq) | 1093.62995 | 67.84892541 | **2418.157676** | 301.757771 | 139.245807 | **441.0035782** | 0 | 0 | 0 | **0** | 137.025688 | 53.0753504 | **190.1010384** | 2789.09221 | 260.170083 | 0 | **3049.262293** |
| Acidification Potential (kg SO2 eq) | 6.505079203 | 0.328572734 | **12.67331235** | 2.40562785 | 0.64407239 | **3.049700239** | 0 | 0 | 0 | **0** | 1.83843593 | 0.24522314 | **2.083659067** | 16.5888034 | 1.21786826 | 0 | **17.80667165** |
| HH Particulate (kg PM2.5 eq) | 1.424247888 | 0.010014124 | **4.652300807** | 0.24497403 | 0.01996085 | **0.264934886** | 0 | 0 | 0 | **0** | 0.04812862 | 0.00760299 | **0.055731617** | 4.93538934 | 0.03757797 | 0 | **4.97296731** |
| Eutrophication Potential (kg N eq) | 0.771591519 | 0.023585697 | **0.933938521** | 0.14271611 | 0.04648434 | **0.18920045** | 0 | 0 | 0 | **0** | 0.12247374 | 0.01770075 | **0.140174496** | 1.17554267 | 0.0877708 | 0 | **1.263313467** |
| Ozone Depletion Potential (kg CFC-11 eq) | 3.67215E-06 | 2.71222E-09 | **1.59996E-05** | 8.129E-07 | 5.5502E-09 | **8.18455E-07** | 0 | 0 | 0 | **0** | 5.9871E-09 | 2.1154E-09 | **8.10249E-09** | 1.6816E-05 | 1.0378E-08 | 0 | **1.68262E-05** |
| Smog Potential (kg O3 eq) | 61.30965318 | 11.62070249 | **143.3251999** | 73.4151703 | 22.7745485 | **96.18971884** | 0 | 0 | 0 | **0** | 65.2118287 | 8.67110248 | **73.88293122** | 270.331496 | 43.0663535 | 0 | **313.3978499** |

**Step 4:** Find an EPD for concrete manufacturing. The EPD/m3 is shown below. I chose the Mix Code: 3F1EG9D1 and Plant: Martinez from Central Concrete at http://www.nrmca.org/sustainability/EPDProgram/Central_Concrete_EPD.pdf
This EPD gave a value for primary energy consumption. The value is incorrect but is used for purposes of illustrating my knowledge to calculate the final impact value.
The was no value given for HH Particulate so I assumed a value of 1 for purposes of this

Test.  The EPD Values are shown below.

| TYPE OF IMPACT | EPD VALUE |
|---|---|
| Fossil Fuel Consumption (MJ)/m3 | 2057 |
| Global Warming Potential (kg CO2 eq)/m3 | 287.3 |
| Acidification Potential (kg SO2 eq)/m3 | 2.502 |
| HH Particulate (kg PM2.5 eq)/m3 | NO VALUES GIVEN. ASSUME SAME VALUE as 1. |
| Eutrophication Potential (kg N eq)/m3 | 0.0854 |
| Ozone Depletion Potential (kg CFC-11 eq)/m3 | 4.023E-06 |
| Smog Potential (kg O3 eq)/m3 | 2.849 |

**Step 5:** Multiply the EPD values by the hollowed out concrete volume.

(Original Concrete Volume 267.5, Concrete Volume With Waste Excluded: 254.78)

| | EPD VALUE | MANUFACTURING |
|---|---|---|
| Fossil Fuel Consumption (MJ)/m3 | 2057 | 524082.46 |
| Global Warming Potential (kg CO2 eq)/m3 | 287.3 | 73198.294 |
| Acidification Potential (kg SO2 eq)/m3 | 2.502 | 637.45956 |
| HH Particulate (kg PM2.5 eq)/m3 | NO VALUES GIVEN. ASSUME SAME VALUE as 1. | 3.218038794 |
| Eutrophication Potential (kg N eq)/m3 | 0.0854 | 21.758212 |
| Ozone Depletion Potential (kg CFC-11 eq)/m3 | 0.000004023 | 0.00102498 |
| Smog Potential (kg O3 eq)/m3 | 2.849 | 725.86822 |

**Step 6:** Re-add the newly calculated impact back into the Step 3 Phase

(The impact values for the formwork, rebar etc. Minus the concrete).

These final values are the new impacts the wall would have if it included 25 MPA instead of 20 MPA as assumed.

| | PRODUCT | | | CONSTRUCTION PROCESS | | | USE | | | | END OF LIFE | | | TOTAL EFFECTS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Summary Measures | Manufacturing | Transport | **Total** | Construction-installation Process | Transport | **Total** | Replacement Manufacturing | Replacement Transport | Operational Energy Use Annual | **Total** | Material | Transport | **Total** | Non-Transport | Transport | Operational Energy Use | **Total** |
| Fossil Fuel Consumption (MJ) | 541040.9537 | 936.0176704 | **541976.9714** | 3906.75483 | 1812.71658 | **5719.471418** | 0 | 0 | 0 | **0** | 2038.5357 | 689.962183 | **2728.49788** | 32170.1815 | 3438.69644 | 0 | **550424.9407** |
| Global Warming Potential (kg CO2 eq) | 74291.92395 | 67.84892541 | **74359.77288** | 301.757771 | 139.245807 | **441.0035782** | 0 | 0 | 0 | **0** | 137.025688 | 53.0753504 | **190.1010384** | 2789.09221 | 260.170083 | 0 | **74990.87749** |
| Acidification Potential (kg SO2 eq) | 643.9646392 | 0.328572734 | **644.2932119** | 2.40562785 | 0.64407239 | **3.049700239** | 0 | 0 | 0 | **0** | 1.83843593 | 0.24522314 | **2.083659067** | 16.5888034 | 1.21786826 | 0 | **649.4265712** |
| HH Particulate (kg PM2.5 eq) | 4.642286683 | 0.010014124 | **4.652300807** | 0.24497403 | 0.01996085 | **0.264934886** | 0 | 0 | 0 | **0** | 0.04812862 | 0.00760299 | **0.055731617** | 4.93538934 | 0.03757797 | 0 | **4.97296731** |
| Eutrophication Potential (kg N eq) | 22.52980352 | 0.023585697 | **22.55338922** | 0.14271611 | 0.04648434 | **0.18920045** | 0 | 0 | 0 | **0** | 0.12247374 | 0.01770075 | **0.140174496** | 1.17554267 | 0.0877708 | 0 | **22.88276416** |
| Ozone Depletion Potential (kg CFC-11 eq) | 0.001028652 | 2.71222E-09 | **0.001028655** | 8.129E-07 | 5.5502E-09 | **8.18455E-07** | 0 | 0 | 0 | **0** | 5.9871E-09 | 2.1154E-09 | **8.10249E-09** | 1.6816E-05 | 1.0378E-08 | 0 | **0.001029481** |
| Smog Potential (kg O3 eq) | 787.1778732 | 11.62070249 | **798.7985757** | 73.4151703 | 22.7745485 | **96.18971884** | 0 | 0 | 0 | **0** | 65.2118287 | 8.67110248 | **73.88293122** | 270.331496 | 43.0663535 | 0 | **968.8712257** |

**Step 7:** The next step would be to upload these results back into Athena

## 4.3 Data Quality

There are 5 different types of uncertainty present in the CEME LCA model, data, model, temporal, spatial and variability. Below is a description of each type of uncertainty present in the model and an example.

### 4.3.1 Data Uncertainty

Data uncertainty is present in two stages of an LCA, the inventory analysis stage and the impact assessment stage.[17] Within the Inventory Analysis Stage, there are four different types: collection, allocation methods used to create data, inaccuracy or no data. All of these stems from an LCI database having either empirical inaccuracy, incomplete or outdated measurements and missing data. Within the Impact Assessment Stage, there are two uncertainties: uncertainty in lifetimes of substances and travel potential. An example that might be present in an LCI database is that data uncertainty might exist from human error. For example, the instrumentation might not be calibrated properly or might be used incorrectly.

### 4.3.2 Model Uncertainty

Model uncertainty could include linear vs. non-linear modeling in the inventory analysis stage and characterization factors may be unknown in the impact assessment stage. [18] The impact estimator assumes that ecological processes act linearly. This is not always the case; in fact many processes are non-linear. [15] Moreover, characterization factors may be incorrect as they are calculated using very simplified environmental models, which in turn have their own uncertainties.[15] A good example of this is that LCA does not take into account the sensitivity of

[17]Sianchuk, R. (2013). *Week 8 – Uncertainty In LCA.* Retrieved from http://civl498c.wikispaces.com/file/view/Week8_Uncertainty.pdf/462592198/Week8_Uncertainty.pdf

[18]Henriksson, J., Guinee, J. Heijungs, R., de Koning, A., and Green, D. (2013). *A Protocol for Horizontal Averaging of Unit Process Data – Including Estimates For Uncertainty.* Retrieved from http://download.springer.com/static/pdf/295/art%253A10.1007%252Fs11367-013-0647-4.pdf?auth66=1384919586_ba8dbe506d38cdf91d24f54e9165ba52&ext=.pdf

the surrounding environment in regards to the computation of acidification factors.[15] It is unlikely that model uncertainty plays a large part in CEME as the building is located in a controlled surrounding environment, with mostly commonly used materials that have common characterization factors.

### 4.3.3 Temporal Uncertainty

Differences in industrial yearly production of factory emissions and data vintage are common temporal uncertainty factors in the inventory analysis stage.[14] For example, LCI commonly uses emission data rates that are determined from taking an average value, dividing emissions overall by production over a certain period of time. [15] Therefore, if more emissions were produced during the first half of the year when a material was purchased, the data would not be accurate. Furthermore, emissions usually differ by year as well, and the mean value is taken over all years of data that have been accumulated. Emissions from an early decade are often very different than modern emissions but only a mean value is usually taken, a cause of data vintage. During the impact assessment stage, the two types of temporal uncertainty are effects of climate and interpretation of impacts over time. For example, wind speed and temperature vary per region but also vary per time periods. As temporal variation is not available over short time periods in the inventory analysis stage, it will affect the impact assessment. Impacts over time uncertainty are caused due to the differences in lifetimes of substance's impact categories, as something like global warming potential differs depending on the time period to investigate effects.

### 4.3.4 Spatial Uncertainty

Spatial uncertainty is caused by regional differences between manufacturing plants. It is caused due to unavailability of data for specific regions, as it is usually unknown. Furthermore, much of the LCA site-specific data is applicable to Europe as it has been calculated using detailed environmental information from that area. However, it might not be applicable to the United States or Canada. For example, Canada might have different eutrophication creation factors than Europe does.

### 4.3.5 Variability Between Objects/Sources Uncertainty

Variability between objects and sources includes differences between factories, different technologies that produce the same product and differences in human exposure patterns. Variability in life cycle inventories will occur due to the different production techniques manufacturing firms use to develop the same product. Human exposure patterns differ as every human varies in body weight, consumption of food, etc. and therefore their human toxicity potential will vary.

#### 4.3.6 Quality of LCI Databases

The quality of the LCI databases is standard. The oldest database as per the Athena Sustainable Materials Institute is from 1999, and on aluminum frames.[19] Most of the databases are very recent and updated, the majority are newer than 2005. For this project, to reduce uncertainty, as a reader one must interpret the LCA results cautiously as many uncertainties are present. CEME draws information from various sections, the largest being from the concrete and steel products sections The quality of those are quite high as they are as recent as 2005 and have been updated from the original 1993 data. Furthermore, they also include production profiles from the US LCI databases, one of the largest existing databases.

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

## 5.0 List of Indicators Used For Assessment And Expression of Results

The impact assessment method used in this project was Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). The impact estimator software used was the Athena Impact Estimator for Buildings Version 4.2.02. The following tables below illustrate the 7 impact categories used in the impact assessment of CEME and include: a general description of the cause/effect chain model, its category indicator and a list of potential endpoint impacts.

***Global Warming Potential[20]***

| | |
|---|---|
| **Impact Category** | Global Warming Potential |
| **Midpoint Impact** | The absorption of infrared radiation. This in turn causes the atmosphere temperature to increase. |
| **Category Indicator** | Kg $CO_2$ eq |
| **Cause/Effect Chain Model** | Emissions to Air → Infrared Radiation Absorbed → Causes increase in global temperature, change in sea levels and precipitation → Leads to human health impacts, agricultural/forestry/special/water resource effects, and coastal area damage. |
| **Potential Endpoint Impact** | - Sea levels rising due to glaciers melting.<br>- Tree mortality decreases due to reduction in water caused by regional warming.<br>- Global precipitation increase.<br>- Floods and droughts becoming more common.<br>- Less fresh water availability.<br>- Changing Ecosystems[21] |
| **Characterized By** | - US EPA – TRACI<br>- Intergovernmental Panel on Climate Change (IPCC) |

**Table 6 - Impact Category - Global Warming**

[20] Sianchuk, R. (2013). *Week 6 – Impact Assessment.* Retrieved from http://civl498c.wikispaces.com/file/view/Week6_Impact%20Assessment.pdf/458461904/Week6_Impact%20Assessment.pdf

[21] National Geographic (2013). *Effects of Global Warming.* Retrieved from http://environment.nationalgeographic.com/environment/global-warming/gw-effects/

*Ozone Depletion Potential*[20]

| | |
|---|---|
| **Impact Category** | Ozone Depletion Potential |
| **Midpoint Impact** | Change in the ozone layer due to emissions of CFC-11 |
| **Category Indicator** | Kg CFC-11 eq |
| **Cause/Effect Chain Model** | Emissions to Air → Causes Reduction of the Ozone Layer in Stratosphere → Increases UBV concentration on earth → Species/Material Damages, Human Health Impacts, Agricultural Effects |
| **Potential Endpoint Impact** | - Human Heath impacts such as UV mutation, skin cancers, etc.<br>- Changes in plant growth – UV lighting activated defence proteins in plants, increases vitamin production, increases/decreases growth rate depending on plant, increases/decreases plan size depending on plant, and affects plant composition. |
| **Characterized By** | - US EPA – TRACI<br>- World Meteorological Organization (WMO) |

**Table 7 - Impact Category - Ozone Depletion**

*Eutrophication Potential*[20]

| | |
|---|---|
| **Impact Category** | Eutrophication Potential |
| **Midpoint Impact** | Effect on algae growth in water bodies with high N and P content. It includes the probability of nitrogen entering a water body. |
| **Category Indicator** | Kg N eq. |
| **Cause/Effect Chain Model** | Water Emissions and presence in water body → Growth of algae and weeds → Oxygen depletion in water due to dead biomass and release of toxins |
| **Potential Endpoint Impact** | - Stratification of warm waters during the summertime. (Hypoxia) |
| **Characterized By** | - US EPA – TRACI |

**Table 8 - Impact Category - Eutrophication Potential**

*Acidification Potential*[20]

| | |
|---|---|
| **Impact Category** | Acidification Potential |

| | |
|---|---|
| **Midpoint Impact** | Effect on increasing the acidity of water and soil due to the formation of acidifying H+ ions in relation to $SO_2$ |
| **Category Indicator** | Kg $SO_2$ eq. |
| **Cause/Effect Chain Model** | Air emissions, the emission surrounding atmospheric concentrations & environment(Including temperature and climate) → Deposition → Leaching of Al, H+ ions, and nutrient cations acidifies water/soil sources→ Causes changes to ecosystem and reduces plant and animal mortality. |
| **Potential Endpoint Impact** | - Acid Rain causes fish/frog mortality to decrease.<br>- Causes plant mortality to decrease. |
| **Characterized By** | - US EPA – TRACI |

**Table 9 - Impact Category - Acidification Potential**

***Smog Formation Potential[20]***

| | |
|---|---|
| **Impact Category** | Smog Potential |
| **Midpoint Impact** | Capacity to influence the photochemical creation of ozone in the troposphere. |
| **Category Indicator** | Kg $O_3$ eq. |
| **Cause/Effect Chain Model** | Air emissions in combination with VOC's/$NO_x$S/Temperature/Sunlight → High ozone concentration in troposphere → Reduced photosynthesis and human's inhaling smog → Decreases human/plant mortality and has negative affects on human health. |
| **Potential Endpoint Impact** | - Causes human health impacts such as Asthma, bronchitis and emphysema and could lead to premature death. |
| **Characterized By** | - Leads to the following negative human health impacts: asthma, heart disease, chronic breathing, emphysema, pneumonia, premature births in pregnant women and low birth weights. |

**Table 10 - Impact Category - Smog Potential**

***Human Health and Respiratory Effects Potential[20]***

| | |
|---|---|
| **Impact Category** | Human Health Criteria - Air |
| **Midpoint Impact** | Capacity to influence human exposure to <10 microns air bourne |

| | |
|---|---|
| | particulate matter. |
| **Category Indicator** | Kg $PM_{2.5}$ eq. |
| **Cause/Effect Chain Model** | Humans inhale air emissions → Human alveoli receive particulate matter → Human body reacts to harmful substances in particulate matter → Causes negative human health impacts |
| **Potential Endpoint Impact** | - Causes human health impacts such as Asthma, bronchitis and emphysema and could lead to premature death. |
| **Characterized By** | - US EPA – TRACI |

**Table 11 - Impact Category - Human Health Criteria**

***Fossil Fuel Consumption***[20]

| | |
|---|---|
| **Impact Category** | Fossil Fuel Consumption |
| **Midpoint Impact** | Feedstock and embodied energy of a material that is used to transform or transport raw materials into a building. |
| **Category Indicator** | MJ – Mega-Joules |
| **Cause/Effect Chain Model** | Construction processes cause energy to be used to create materials and to construct buildings → energy and electricity used → energy used from fossil fuels causes $CO_2$ emissions→ Same endpoints as global warming, water and land pollution, etc. |
| **Potential Endpoint Impact** | - Water and Land Pollution<br>- Thermal Pollution<br>- National Security Impacts.[22] |
| **Characterized By** | - Unique to Athena Sustainable Materials Institute as it directly relates to building construction. |

**Table 12 - Impact Category - Fossil Fuel Consumption**

[22] Union of Concerned Scientists (2002). *The Hidden Cost of Fossil Fuels.* Retrieved from http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/the-hidden-cost-of-fossil.html

# 6.0 Model Development

The following sections will describe first how the original model was developed and then how it was improved and resorted using CIQS format.

## 6.1 Original Model Development

The first author, Tyler Algeo, used OnScreen Takeoff Version 3.6.2.25 to model CEME. The drawings used are illustrated in the table below and were compiled from the UBC LBS Facilities and Capitol Planning Records Department:

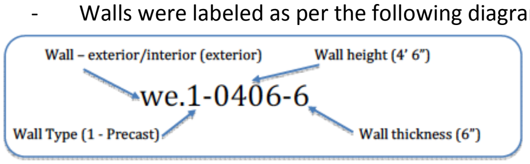
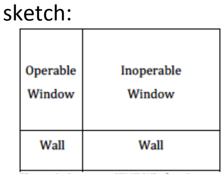
| Drawing Label | Description of Drawing |
|---|---|
| 306-06-008 | Overview of Site Plan |
| 306-06-009 | Area 4 – Ground Floor Plan |
| 306-06-010 | Area 1 and Area 5 – Ground Floor Plan |
| 306-06-011 | Area 2 – Ground Floor Plan |
| 306-06-012 | Area 5 – Ground Floor Plan |
| 306-06-013 | Area 4 – Second Floor Plan |
| 306-06-014 | Area 2 – Second Floor Plan |
| 306-06-015 | Area 3 – Second Floor Plan |
| 306-06-016 | Area 2 – Basement, Penthouses |
| 306-06-017 | All Areas – Roof Plan |
| 306-06-018 | All Areas – Building Sections |
| 306-06-019 | Area 1 and Area 2 – Building Sections |
| 306-06-020 | All Areas – Elevations Part 1 |
| 306-06-021 | All Areas – Elevations Part 2 |
| 306-06-022 | All Areas - Wall Sections |
| 306-06-025 | All Areas – Window Details |
| 306-06-026 | All Areas – Stair Details |
| 306-06-029 | All Areas – Building Details |
| 306-07-002 | All Areas – Foundation Layout Part 1 |
| 306-07-003 | All Areas – Foundation Layout Part 2 |
| 306-07-004 | All Areas – Foundation Layout Part 3 |
| 306-07-005 | All Areas – Foundation Layout Part 4 |
| 306-07-006 | Area 2 – Structural Ground Floor |
| 306-07-007 | Area 3 – Structural Ground Floor |
| 306-07-008 | Area 4 – Structural Ground Floor |
| 306-07-009 | Area 5 – Structural Ground Floor |

Table 13 - List of CEME Drawings Used In LCA

OnScreen Takeoff was used to model the elements in the following assembly groups: Foundations, Floors, Walls, Columns and Beams, Roofs, and Extra Basic Materials. The elements were then recorded in the “Annex D - Inputs and Assumptions Document” for the original measurements taken in the OnScreen Takeoff. Then the elements were inputted into the Athena Impact Estimator. Due to limitations of Athena, many of the inputs had to be manipulated in order to obtain the correct volumes and areas. The changes made from the actual values measured in OnScreen Takeoff to the ones inputted in Athena are also recorded on the Annex D document. A separate "Assumptions" tab records any assumptions made for each element.

### 6.1.1 Original Model Assembly Groups

The following table describes how the original model was labeled.

| **Assembly Group** | **Labeling** | **Modeling Information** |
|---|---|---|
| *Foundations* | - On-Grade slabs were based on thickness of slab, Ex. "OnGradeSlab1-4 was a 4" slab.<br>- Three types of footings were present: Column, Strip Footings and Basement Walls.<br>- Column footings formatted "f.#" where the number corresponded to the number of footings in the drawings.<br>- Strip Footings formatted "f.A" where the letter A would change depending on what type of strip footing it was.<br>- Basement walls used same labeling as Strip Footings | - Foundation Slabs modeled using Area Condition on OnScreen Takeoff<br>- Column Footings modeled using Count Condition<br>- Strip Footings modeled using linear condition. Volumes of strip footings were summed and broken down and adjusted for the IE.<br>- See Assumptions Annex D for further information. |
| *Floors* | - Named using short form of what they represent. For example "SuspSlab" represented suspended slab. | - Suspended Slabs, Precast concrete T-Beams and Slabs on Grade modeled using Area Condition of Onscreen.<br>- Stairs were modelled as a footings by approximating the thickness and then measured angularly to find the volume.<br>- T-beam floors were divided into a small span and long length to ensure they could be inputted into impact estimator (But retained the same area) |
| *Walls* | - Walls were labeled as per the following diagram:<br><br>**Figure 1: Wall Takeoff Nomenclature**<br>Each wall type corresponds to the following labeling:<br>- 1- Precast<br>- 2-Concrete Block<br>- 3- Poured Concrete Wall<br>- 4- Wood Stud Wall<br>- 5- Concrete Block Fire Wall<br>- 6-Partial Height Wood Stud Wall<br>- 7- Wood Stud Wall with Type 1 Insulation<br>- 8- Wood Study Wall with Type 2 Insulation<br>- 9- Steel Stud Wall<br>- 10- Steel Stud Partition Wall<br>- 11- Steel Stud Partition Wall With Fiberglass Insulation | - Doors were counted and measured in OnScreen Takeoff using the Count Condition.<br>- Walls were measured in OnScreen Takeoff using the Linear Condition.<br>- Concrete block walls were estimated to have a longer length to accommodate for the fact that they are only supposed to be 200mm in length but the impact estimator only allows 6in or 8in thicknesses.<br>- Windows in CEME typically illustrated as per below sketch:<br><br>- The Wall section of the above window could not be modeled in IE as each wall assembly only has one window imput, therefore the materials were added into "Extra Basic Materials"<br>- All windows were considered to be inoperable |

| | | |
|---|---|---|
| | | in the model to simplify the inputs.<br>- See Assumptions Annex D for further information. |
| *Columns and Beams* | - Columns labeled as "C.#." or "C.#.#"<br>- The first # corresponds to each building area (1, 2, 3, 4, 5) while the second represents corresponds to the level (First Floor, Second Floor, Basement, Penthouse) | - Columns counted using OnScreen Takeoff Count Condition<br>- Supported Area was calculated using OnScreen Takeoff Area Condition.<br>- See Assumptions Annex D for further information. |
| *Roofs* | - The only roof type modeled was the Open Web Steel Joist. | - Roof was modeled using the Area condition of OnScreen Takeoff Area Condition. |
| *Extra Basic Materials* | - Gypsum Board, Insulation, Steel and Wood were the extra materials modeled for the windows. They are labeled accordingly. | - Used to model the window condition wall section as per the "Walls" subsection. |

**Table 14 - Original Model Assembly Groups**

### 6.1.2 Inaccuracies in the Original Model

The interpretation of CEME's drawings posed the largest number of inaccuracies in the model. Many assumptions needed to be made about every single assembly characteristic, such as assuming the rebar used is #4 and that the live loads are assumed to be 75 psi. There is no way to check these numbers without the full set of drawings, which were not available. There were also elements present in the model that was outside of the ability for the Impact Estimator to Model, or outside of the scope of the assessment. These most significant one that is excluded is the underside of the overhangs in CEME are too complex for the Impact Estimator to model as they are made from plaster. Furthermore, the foundations were treated to have a constant thickness while in actuality they have a variety due to their function of accommodating different large lab equipment. Moreover, the penthouses located on the roof were unable to be modeled as there were corrugated metal sheeting around a frame of columns and open webbed steel joists, and the impact estimator did not have the capacity to include the unique wall envelope, only the columns. Another inaccuracy introduced from the original model was that the drawings were hand drawn and scanned, which added difficulty when trying to find limits during measuring of objects.

## 6.2 CIQS Sorting

The re-sorted Level 3 elements can be found in Annex D – Impact Estimator Inputs and Assumptions. The following table below gives a brief description of what is included in each CIQS category for CEME.

| LEVEL 3 ELEMENT | WHAT IS INCLUDED IN THIS CATEGORY SPECIFIC TO CEME |
|---|---|
| A11 Foundations | - Column Footings |

| | |
|---|---|
| | - Strip Footings |
| A21 Lowest Floor Construction | - Slab on grade<br>- Mezzanine Floor Slab |
| A22 Upper Floor Construction | - All Second Level Floors<br>- All Penthouse Floors<br>- All Columns and Beams Supporting the Upper Floors (Excluding columns and beams supporting the roof) |
| A23 Roof Construction | - Roofing structural frame and insulation<br>- Assumed Roofing Membrane<br>- All Columns and Beams Supporting the Roof Structure |
| A31 Walls Below Grade | - All exterior walls in the basement level.<br>- Corresponding windows and doors. |
| A32 Walls Above Grade | - All exterior walls above grade.<br>- Corresponding windows and doors. |
| B11 Partitions | - All Interior walls above and below grade. |

**Table 15 - CIQS Elements**

## 6.3 Model Improvements

Unfortunately, the previous OST for CEME became corrupted and was lost. Therefore the previous author's version of OnScreen Takeoff 3.6.2.25 could not be used with the newer version of OnScreen Takeoff 3.9. It was assumed that his results were accurate unless proven otherwise. Below is a table that illustrates the upgrades to the original model that were made. These improvements are also found in Annex D – Impact Estimator Inputs and Assumptions that outlines the changes in further detail.

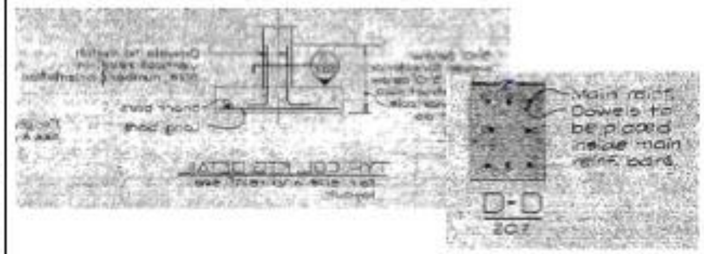
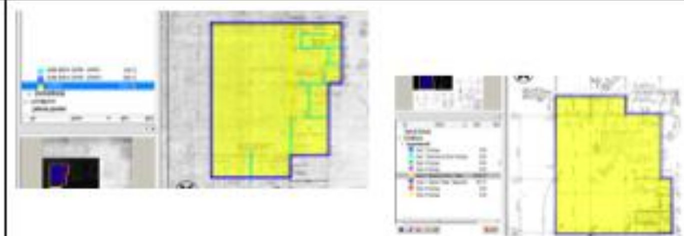
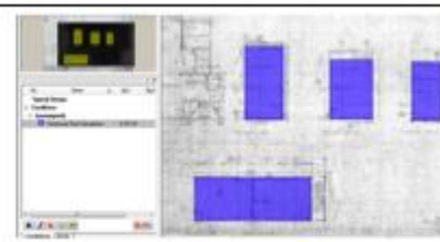
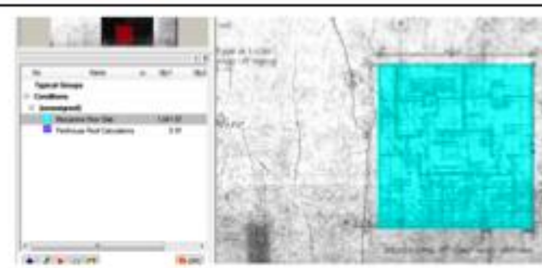
| Improvements to Make | How I Improved The Model. | Picture of Footing Used For Assumption | Results From Takeoff |
|---|---|---|---|
| Tyler stated in previous report: "The column footing model does not include the section of the column that extends below the ground of the footing, which was left out due to insufficient drawing detail. | As there is no footing schedule, to improve the model to include the footing undernead the ground, I assumed a conservative measurement for each footing based on the Typical Column footing detail D-D located on drawing 306-07-202. As I don't have the previous OST file, I started a new OST and measured the dimensions of the footing underneath the ground to be 1' x 2' x 3'. I then counted the footings for each area. As per the typical footing detail, I also added 8 #4 rebar - 3 ft long as per the cross section which classifies them as 'long' rebar. I then added this footing value to the Athena Impact Estimator by finding the total area of all footings per area (Areas defined on drawings) and adding them by area. |  | Area 1 Footings: 52, Area 2 Footings: 18, Area 3 Footings: 31, Area 4 Footings 39, Area 5 Footings: 17 |
| Tyler modelled the basement walls as footings as per his assumption on Page 13. They need to be changed as they should be modelled as walls. | I had to perform a new OST to double check the wall calculation. I then deleted the "Basement Walls" section modelled as a footing from the Athena file and replaced it with a new file with the new measurements modelled as a wall. |  | Area 2 Basement Walls: 298 lf, Area 4 Basement Walls: 357 lf. There is no basement for Areas 1, 3, and 5. |
| Double Check Penthouse Roof Calculations. Tyler had 6441.6 sf for the pent house roofs, when the actual value was 5257 sf. | Calculated actual square footage for penthouse roofs. Divided each penthouse roof by area. Modified each penthouse to be unique so it could have correct dimensions. Changed to steel materials. |  | Total Area for Penthouses: 5275 sf. |
| Mezzanine Not Included In Floor Slab Calculations | Added Mezzanine Floor Slab. |  | Mezzanine Floor Slab = 35'7" x 39'9" |

**Table 16 - Detailed Description of CEME Model Improvements**

## 6.4 Reference Flow and Bill of Materials

A reference flow is defined as the measure of the outputs that fulfills the function expressed by the functional unit in a given product system[23] The purpose of a reference flow is to decipher the functional unit into particular product flows.[24] In CEME's case, the reference flow is a materials list of the product, which is the overall building and envelope. The following table illustrates the bill of materials/reference flow per Level 3 Element for CEME.

| **Level 3 Element** | **Materials** | **Quantity** | **Units** |
|---|---|---|---|
| A11 Foundations | Concrete 30 MPa (flyash av) | 504.45 | m3 |
| | Rebar, Rod, Light Sections | 1.46 | Tonnes |
| A21 Lowest Floor Construction | 6 mil Polyethylene | 2282.06 | m2 |
| | Concrete 20 MPa (flyash av) | 251.12 | m3 |
| | Welded Wire Mesh / Ladder Wire | 1.94 | Tonnes |
| A22 Upper Floor Construction | Concrete 30 MPa (flyash av) | 1235.20 | m3 |
| | Hollow Structural Steel | 6.16 | Tonnes |
| | Rebar, Rod, Light Sections | 107.63 | Tonnes |
| A23 Roof Construction | #15 Organic Felt | 28426.93 | m2 |
| | 24 Ga. Steel Roof (Commercial) | 877.72 | m2 |
| | Ballast (aggregate stone) | 275598.34 | kg |
| | Concrete 30 MPa (flyash av) | 894.20 | m3 |
| | Extruded Polystyrene | 6550.44 | m2 (25mm) |
| | Galvanized Decking | 42.83 | Tonnes |
| | Galvanized Sheet | 4.95 | Tonnes |
| | Modified Bitumen membrane | 1615.61 | kg |
| | Nails | 2.14 | Tonnes |
| | Open Web Joists | 38.90 | Tonnes |
| | Precast Concrete | 31.67 | m3 |
| | Rebar, Rod, Light Sections | 235.15 | Tonnes |
| | Roofing Asphalt | 83877.45 | kg |
| | Screws Nuts & Bolts | 0.01 | Tonnes |
| | Solvent Based Alkyd Paint | 468.80 | L |
| | Type III Glass Felt | 56853.86 | m2 |
| | Welded Wire Mesh / Ladder Wire | 0.40 | Tonnes |
| A31 Walls Below Grade | Concrete 20 MPa (flyash av) | 149.88 | m3 |
| | Rebar, Rod, Light Sections | 0.07 | Tonnes |

[23]Sianchuk, R. (2013). *Week 8 – Uncertainty In LCA.* Retrieved from http://civl498c.wikispaces.com/file/view/Week8_Uncertainty.pdf/462592198/Week8_Uncertainty.pdf

[24] Weidema, B., Wenzel, H., Petersen, C., Hansen K. (2004)._*The Product, Functional Unit and Reference Flows in LCA.* Retrieved from http://www2.mst.dk/Udgiv/Publications/2004/87-7614-233-7/pdf/87-7614-234-5.PDF

| | | | |
|---|---|---|---|
| A32 Walls Above Grade | 1/2" Regular Gypsum Board | 5134.75 | m2 |
| | 3 mil Polyethylene | 476.46 | m2 |
| | Aluminum | 44.95 | Tonnes |
| | Concrete 20 MPa (flyash av) | 747.66 | m3 |
| | Double Glazed No Coating Air | 2054.36 | m2 |
| | EPDM membrane (black, 60 mil) | 3074.58 | kg |
| | Expanded Polystyrene | 136.71 | m2 (25mm) |
| | Extruded Polystyrene | 4390.83 | m2 (25mm) |
| | FG Batt R11-15 | 1622.95 | m2 (25mm) |
| | Galvanized Sheet | 2.60 | Tonnes |
| | Galvanized Studs | 1.58 | Tonnes |
| | Joint Compound | 5.12 | Tonnes |
| | Nails | 3.00 | Tonnes |
| | Paper Tape | 0.06 | Tonnes |
| | Rebar, Rod, Light Sections | 36.79 | Tonnes |
| | Screws Nuts & Bolts | 0.07 | Tonnes |
| | Small Dimension Softwood Lumber, kiln-dried | 0.05 | m3 |
| | Solvent Based Alkyd Paint | 12.38 | L |
| | Water Based Latex Paint | 2.80 | L |
| B11 Partitions | 1/2" Regular Gypsum Board | 6974.37 | m2 |
| | 5/8" Regular Gypsum Board | 157.90 | m2 |
| | Concrete 20 MPa (flyash av) | 256.46 | m3 |
| | Concrete Blocks | 33835.43 | Blocks |
| | Double Glazed No Coating Air | 0.10 | m2 |
| | Expanded Polystyrene | 13.02 | m2 (25mm) |
| | Extruded Polystyrene | 521.47 | m2 (25mm) |
| | FG Batt R11-15 | 6804.86 | m2 (25mm) |
| | Galvanized Sheet | 17.18 | Tonnes |
| | Galvanized Studs | 2.69 | Tonnes |
| | Joint Compound | 7.12 | Tonnes |
| | Mortar | 647.02 | m3 |
| | Nails | 1.62 | Tonnes |
| | Oriented Strand Board | 1906.92 | m2 (9mm) |
| | Paper Tape | 0.08 | Tonnes |
| | Rebar, Rod, Light Sections | 132.67 | Tonnes |
| | Screws Nuts & Bolts | 0.12 | Tonnes |
| | Small Dimension Softwood Lumber, kiln-dried | 76.94 | m3 |
| | Solvent Based Alkyd Paint | 74.28 | L |
| | Water Based Latex Paint | 176.54 | L |

**Table 17 - Bill of Materials for CEME**

# 7.0 Communication and Assessment of Results

## 7.1 Life Cycle Results

The following figures below displays the building results for CEME. Each impact category (Fossil Fuel Consumption, Global Warming etc.) is expressed as a total of 100%, with the percentage displayed for each level 3 elements. A summary table is also provided to show where the data was contrived. As shown below, in CEME, the element with the largest impact in all categories is the A22 Upper Floor Construction. This is probably because CEME has a large surface area. In regards to life cycle stages, the largest 'hotspot' impacts come from the manufacturing stages over the construction stages. As we determined to use a service life input of 1 year, the use and end of life stages will have little to no impact.

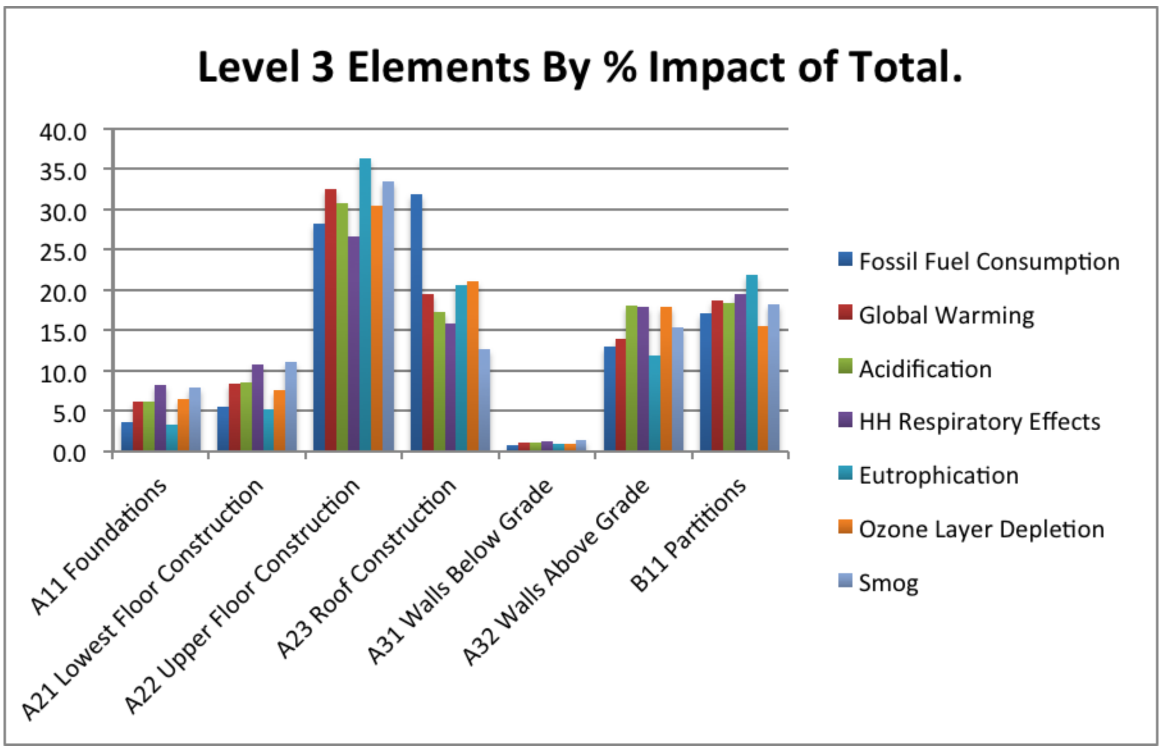



Figure 4 - Level 3 Elements By % Impact of Total Impact Category

| | Fossil Fuel Consumption | Percentage | Global Warming | Percentage | Acidification | Percentage | HH Respiratory | Percentage | Eutrophication | Percentage | Ozone Layer Depletion | Percentage | Smog | Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (MJ) | % | (kg CO2eq) | % | (moles of H+eq) | % | (kg PM10eq) | % | (kg Neq) | % | (kg CFC-11eq) | % | (kg O3eq) | % |
| A11 Foundations | 1110126.93 | 3.6 | 151704.1056 | 6.2 | 1032.50658 | 6.2 | 352.760345 | 8.3 | 47.0752011 | 3.3 | 0.000772141 | 6.5 | 24784.108 | 7.9 |
| A21 Lowest Floor Construction | 1717008.961 | 5.5 | 203558.1601 | 8.3 | 1413.109036 | 8.4 | 455.6418455 | 10.7 | 72.2942456 | 5.1 | 0.000899181 | 7.6 | 34875.5057 | 11.1 |
| A22 Upper Floor Construction | 8790328.105 | 28.2 | 796421.8465 | 32.5 | 5137.719045 | 30.7 | 1137.719915 | 26.7 | 513.547042 | 36.3 | 0.003614713 | 30.5 | 105249.812 | 33.5 |
| A23 Roof Construction | 9952991.027 | 31.9 | 476959.238 | 19.4 | 2896.625645 | 17.3 | 674.8783929 | 15.8 | 292.660473 | 20.7 | 0.002499943 | 21.1 | 39711.1974 | 12.6 |
| A31 Walls Below Grade | 234616.9352 | 0.8 | 24773.07364 | 1.0 | 173.7651849 | 1.0 | 53.22292293 | 1.2 | 12.0688636 | 0.9 | 0.000104367 | 0.9 | 4200.15362 | 1.3 |
| A32 Walls Above Grade | 4055133.507 | 13.0 | 342723.9213 | 14.0 | 3010.677596 | 18.0 | 763.6939485 | 17.9 | 167.616286 | 11.8 | 0.00211271 | 17.8 | 48204.2671 | 15.3 |
| B11 Partitions | 5326507.244 | 17.1 | 457793.5617 | 18.7 | 3067.65166 | 18.3 | 831.1097712 | 19.5 | 310.537926 | 21.9 | 0.001839863 | 15.5 | 57415.298 | 18.3 |
| TOTAL | 31186712.71 | 100.0 | 2453933.907 | 100.0 | 16732.05475 | 100.0 | 4269.027141 | 100.0 | 1415.80004 | 100.0 | 0.011842918 | 100.0 | 314440.342 | 100.0 |

Table 18 - Level 3 Elements By % Impact In Table Format

This concludes the building declaration section of the report. The next four sections that are included are Annexes that are a reflection of the author's experience as well as a further interpretation of the results and how they can be used effectively in society. The annexes are as follows:

1. Interpretation of Assessment Results
2. Recommendations for LCA Use
3. Annex C – Author Reflection
4. Annex D – Impact Estimator Inputs and Assumptions

# 8.0 Annex A – Interpretation of Assessment Results

## 8.1 Benchmark Development

Benchmarking is useful in LCA as it is an iterative tool that allows industry professionals, researchers and the general public to easily make sense of LCA-based information. It allows individuals to compare their products impacts with another products impacts.[25] In the case of CEME, it can be compared to other buildings at UBC, in terms of the 7 environmental impacts illustrated in Section 5.0 of this report. The most beneficial tool of a benchmark is to allow individuals to easily interpret the results of an LCA analysis, as many find it easier to compare a result to a benchmark that represents an average, rather than just looking at a number that represents global warming potential. The functional equivalence of a benchmark normalizes the data.

Defining the goal and scope of a project is important for model development as well as benchmark development. When developing the goal, the following question must be asked, "Where will the information be put to use?" In CEME's case, the information will be used for comparative assertions with the other 22 buildings being evaluated, which is defined under the goal category in ISO 14044. The goal will state the reasons for carrying out the study instigate discussion and determine the intended audience all of which are necessary to determine what will be compared for the benchmark. The scope definition will define what is being included in the benchmark, what is to be compared.

## 8.2 UBC Academic Building Benchmark

### 8.2.3 Comparing CEME to UBC Building Benchmark

The following table and chart below illustrates CEME compared to the class benchmark. The following buildings were not included in this graph due to lack of information uploaded in stage 4: Chemistry North, Wesbrook, Geography, Chemistry South Wing, Pharmacy, Douglas Kenny.

[25] Nissinen, A., Heiskanen, E., Grönroos, J., Honkanen, A., Katajajuuri, J.-M., Kurppa, S. (2009). - *Developing LCA-based benchmarks for sustainable consumption for and with users* Retrieved from http://orgprints.org/11268/1/LCA.pdf

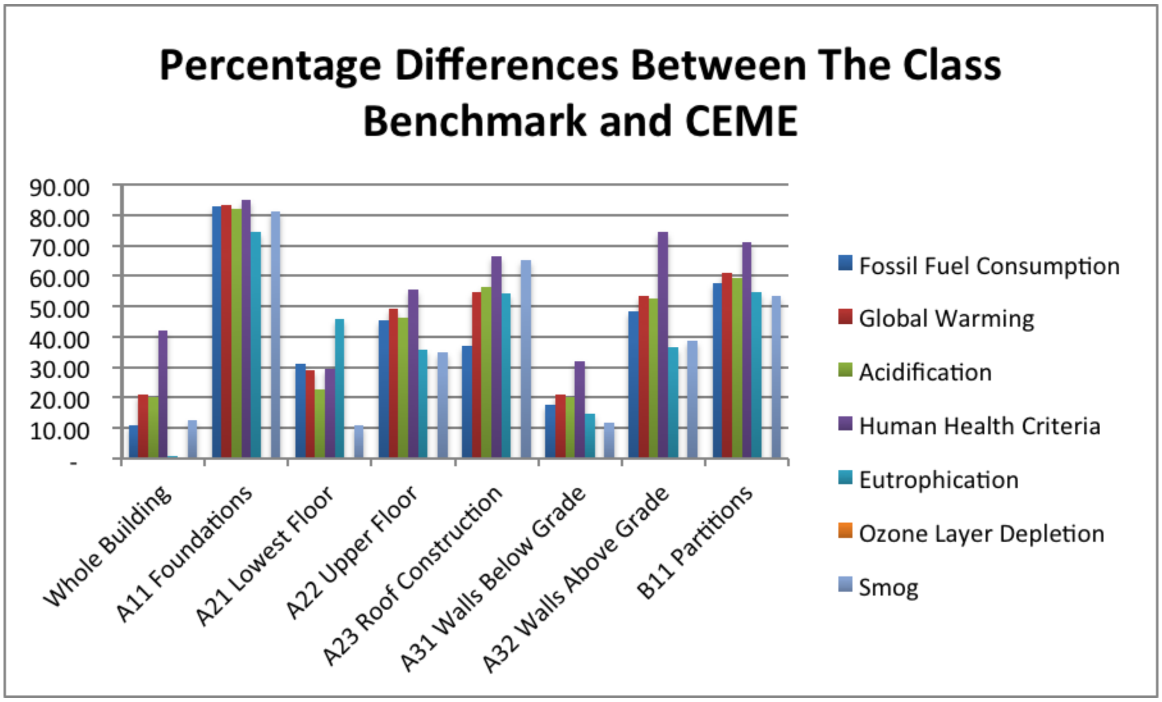



**Figure 5 - Percentage DIfferences Between CEME and Class Benchmarks Illustrated In a Graph**

| CIQS Level 3 Element | Building | Fossil Fuel Consumption | Global Warming | Acidification | Human Health Criteria – Respiratory | Eutrophication | Ozone Layer Depletion | Smog |
|---|---|---|---|---|---|---|---|---|
| | | (MJ) | (kg CO2eq) | (moles of H+eq) | (kg PM10eq) | (kg Neq) | (kg CFC-11eq) | (kg O3eq) |
| Whole Building | Benchmark | 4,555.82 | 386.82 | 2.68 | 0.96 | 2.01E-01 | 1.61E-06 | 45.54 |
| | CEME | 4,106.60 | 306.02 | 2.14 | 0.56 | 0.2 | 0 | 39.79 |
| A11 Foundations | Benchmark | 979.55 | 139.47 | 0.88 | 0.33 | 3.88E-02 | 7.40E-07 | 20.04 |
| | CEME | 169.35 | 23.14 | 0.16 | 0.05 | 0.01 | 0 | 3.78 |
| A21 Lowest Floor Construction | Benchmark | 379.95 | 43.79 | 0.28 | 0.10 | 1.85E-02 | 2.09E-07 | 5.96 |
| | CEME | 261.92 | 31.05 | 0.22 | 0.07 | 0.01 | 0 | 5.32 |
| A22 Upper Floor Construction | Benchmark | 2,291.89 | 222.78 | 1.36 | 0.36 | 1.09E-01 | 5.18E-07 | 23.08 |
| | CEME | 1,254.69 | 113.68 | 0.73 | 0.16 | 0.07 | 0 | 15.02 |
| A23 Roof Construction | Benchmark | 3,695.56 | 244.35 | 1.55 | 0.48 | 1.52E-01 | 1.13E-06 | 26.49 |
| | CEME | 2,322.16 | 111.28 | 0.68 | 0.16 | 0.07 | 0 | 9.27 |
| A31 Walls Below Grade | Benchmark | 638.16 | 70.17 | 0.49 | 0.18 | 2.62E-02 | 3.73E-07 | 8.40 |
| | CEME | 524.75 | 55.41 | 0.39 | 0.12 | 0.03 | 0 | 9.39 |
| A32 Walls Above Grade | Benchmark | 1,300.08 | 121.24 | 1.05 | 0.51 | 4.71E-02 | 6.08E-07 | 12.95 |
| | CEME | 669.63 | 56.59 | 0.5 | 0.13 | 0.03 | 0 | 7.96 |
| B11 Partitions | Benchmark | 1,337.24 | 124.59 | 0.81 | 0.31 | 6.62E-02 | 4.68E-07 | 13.18 |
| | CEME | 568.87 | 48.89 | 0.33 | 0.09 | 0.03 | 0 | 6.13 |

**Table 19 - Benchmark Values Compared To Level 3 Elements**

The Level 3 Element with the largest percent difference from the benchmark value is A11 Foundations. This could be due to the lack of detailed footing drawings for the building. I improved this value as outlined in Section 6.0 as the previous author of this report did not include any material of the footings below the ground. However, there is still a large difference between the benchmark. With more detailed drawings, a better representation of CEME's footing structure could be developed and more likely it would be a smaller percentage difference from the benchmark. A lot of the categories have a large percentage difference with the benchmark as well, such as A23, A32, and B11. This could be due to the large amount of concrete used in the building structure.

### 8.2.3 UBC Building Global Warming Vs. Cost Impacts

The figure below compares the difference between total cost and global warming potential of a building for all the buildings at UBC. Generally, the graph shows a trend that the more money a building costs, the higher the global warming impact it will have on the environment. This makes sense as when a building costs more, it uses more materials and therefore has a larger impact on the environment. CEME is on the bottom half of the trendline. This is probably due to the fact that it is mostly constructed out of concrete, which is a relatively cheap material. It follows the trendline accurately.

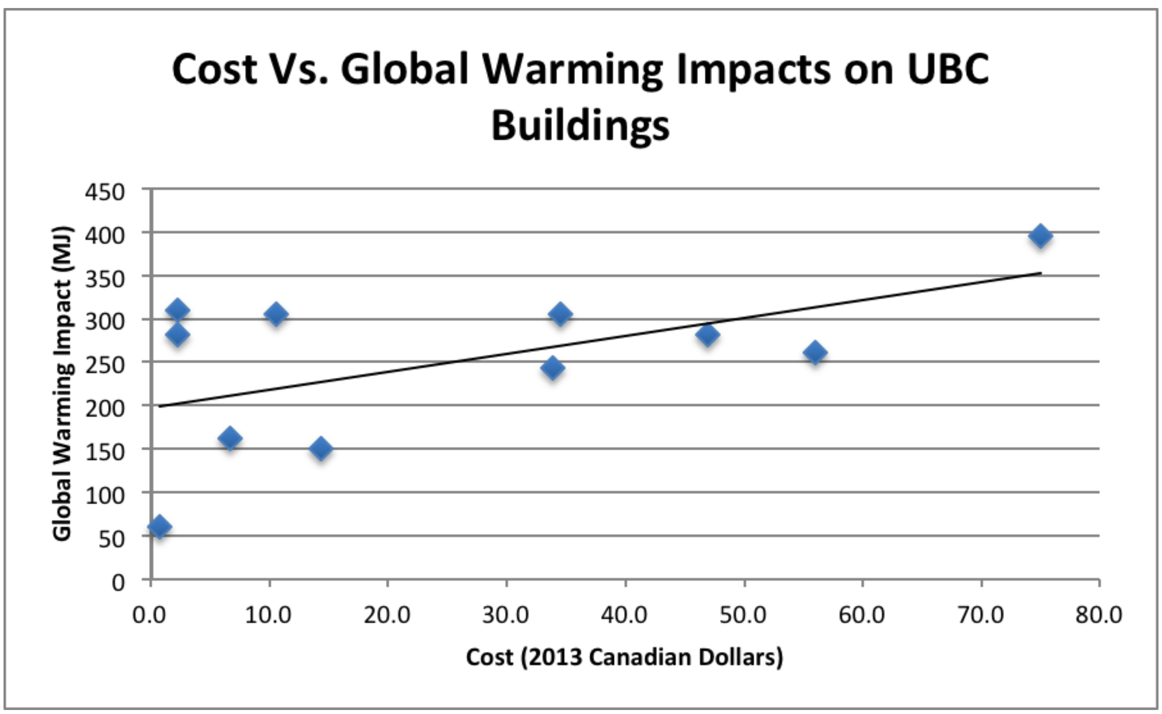



Figure 6 - Global Warming Impact Vs. Cost

# 9.0 Annex B – Recommendations for LCA Use

The following topics discuss the recommendations to operationalize LCA in building design.

## 9.1 Importance of Life Cycle Modules Beyond Product and Construction Stages

The scope of this assessment did not include the life cycle modules beyond the cradle to gate stages; it only included the product and construction modules. However, it is very important to consider the use and end of life modules as they have to account for a large amount of environmental impacts. For example, the use stage includes maintenance, repair, replacement and refurbishment stages. Many products have replacement cycles, meaning they need to be replaced after a certain time period as they are no longer functional. Over the lifetime of a building, a product could be replaced a number of times, could add additional product and construction stages to the buildings overall impact. If mechanical systems are included in a buildings life cycle analysis, the operation and maintenance stages have an even larger impact than the construction stages. Furthermore, at the end of life stage, an extremely large amount of energy is used to disassemble a building. This stage includes de-construction demolition, transport, waste processing and disposal. All of these stages have a significant impact. For example, imagine how many times it would take a single dump truck to remove all the debris from a large high rise that was demolished. The use and end of life cycles have a large contribution to a buildings overall impact, and therefore must be considered.

## 9.2 LCA Applied in Design to Manage the Environmental Performance of Buildings

By using LCA as a tool for competitive assertions, during the design stage, users can compare their buildings design to current buildings in practice to see how they measure up. By using the impact estimator, users can determine which components contribute the largest impacts on the environment. They then can manipulate their building design in the impact estimator using a trial and error process to decrease their components impacts.

## 9.3 Availability and Quality of Data and Benchmarks

In the case of this study, we have used a benchmark value consisting of 22 buildings that are contained at UBC. In practice currently, there is a much larger surplus of benchmarks available for European buildings than for American buildings.[26] There are many building benchmarks available, but not all can be applied appropriately to any building LCA study, it depends on the context. For example, a residential building benchmark would not be applicable in the LCA study of CEME. Appropriate benchmarking for buildings must ensure the buildings are the same time, for example if they are all institutional building, and must also have the buildings place in the same geographical area with similar climates.[27] For products, when using a benchmark value, the product must have the same use function (the reason the functional unit is defined). There are many benchmarks available in products currently, but they all vary in type.

## 9.4 Issues in Application

In this study, the impact categories we prioritized were the ones included in TRACI as well as Fossil Fuel Consumption, which is included in the Athena Impact Estimator. However, issues in real life application arise in choosing which impact categories are most important as individual's opinions are influenced by their own personal experiences. For example, during an CIVL 498C lecture, an aversion survey was performed by the class. During this exercise, the students were asked to rank the value they put on importance for each impact category listed. The activity was done as a personal reflection. After they were completed, the students were told to discuss with their groups why they chose what they did and to re-rank the categories. After re-ranking, almost every student changed his or her original numbers. This was because many presented reasonable arguments that the other group members might not have thought of. For example, after individual ranking and speaking with my group, there was a person who's sister who developed a lung condition due to HH particulates in the air in China. I then gave a higher ranking to the HH Particulates as her story inspired me to. Therefore, the issues in application/interpretation can vary according to whom is deciding their importance.

## 9.5 Steps to Operationalize LCA Methods

The steps I would take to operationalize LCA methods at UBC are as follows:

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[26] De Cristofar, L., Konig, H., (2012). *Benchmarks for Life Cycle Costs and Life Cycle Assessment of Residential Buildings.* Retrieved from http://www.tandfonline.com/doi/pdf/10.1080/09613218.2012.702017

[27] Peng, T. National Ready Mixed Concrete Association (2011) – *MIT Research: Life Cycle Assessment of Residential Buildings.* Retrieved from http://www.nrmca.org/sustainability/CSR06%20-%20MIT%20Research%20LCA%20of%20Residential%20Buildings.pdf

- Conduct a separate LCA study on all UBC buildings to determine a benchmark value (As determined in this study) Have an individual with LCA professional background (Rob Sianchuk) to check over the study to determine they are accurate.
- Use this benchmark value to determine where UBC's buildings currently fall in comparison to other universities.
- Every time a new building is being considered, use the UBC building benchmark value to determine where UBC's buildings fall in comparison to the previous buildings at UBC.
- Ensure architect and engineers have the information from the LCA benchmarks so they can use this information to influence their design when working for UBC.

# 10.0 Annex C - Author Reflection

## 10.1 Previous Experience

My only previous exposure to LCA prior to this class was learning about it in my LEED Green Building Associates Prep class given by UBC Continuing Studies. Life Cycle Analysis was introduced in the "Materials and Resources" module and how it can be applied in LEED. In this class I learned about what LCA was and how LCA can be used in practical design to compare various products. It introduced the limitations to LCA and a brief overview of the process to perform one. Furthermore the class introduced the comparison tool BEES and the Athena Impact Estimator. In respect to sustainability, since the beginning of my term as a civil engineering student at UBC sustainability in building design has been a major focus. I have taken a couple classes regarding sustainability, including CIVL 201 and CIVL 202, and at present CIVL 405.

## 10.2 Overview of CIVL 498C

CIVL 498C focuses on giving student an overview of what LCA is. It provides students with an understanding of the standards and methodologies of LCA and how to interpret/understand LCA studies. The course progressed through four main topics, including the history/current state of LCA, the overall structure of LCA through a detailed explanation of ISO 14044 and 14040, the development of a whole building LCA study and uncertainty in current LCA practices.

## 10.3 Interest in CIVL 498C and LCA of A Building

What interested me most about CIVL 498C was that we were going to learn about how to perform our own LCA study on a building at UBC. I thought this would be an applicable skill to have, especially for future LEED projects I might get to work on. Furthermore, I thought it would be interesting to look at some of the building drawings at UBC to expand on my skills of identifying materials in structures and my onscreen takeoff skills. Below are two graphs illustrating the differences from my expectations from before the project compared what I actually learned after performing the final project. The biggest change as illustrated in the graphs is the amount I actually learned about the LCA process. In class we got a brief overview of many topics, but what I liked about the final project was that I learned about certain subjects such as uncertainty and LCI Databases in further detail. Moreover, I found we got an overview of what last years students did, and we could contribute ourselves to their previous reports.

This made my work feel productive, as I was not just repeating work they had already done, but I was contributing my own ideas and improving on the previous author's model.  That is why I increased the percentage of "Analyzing the Results of a LCA Study."

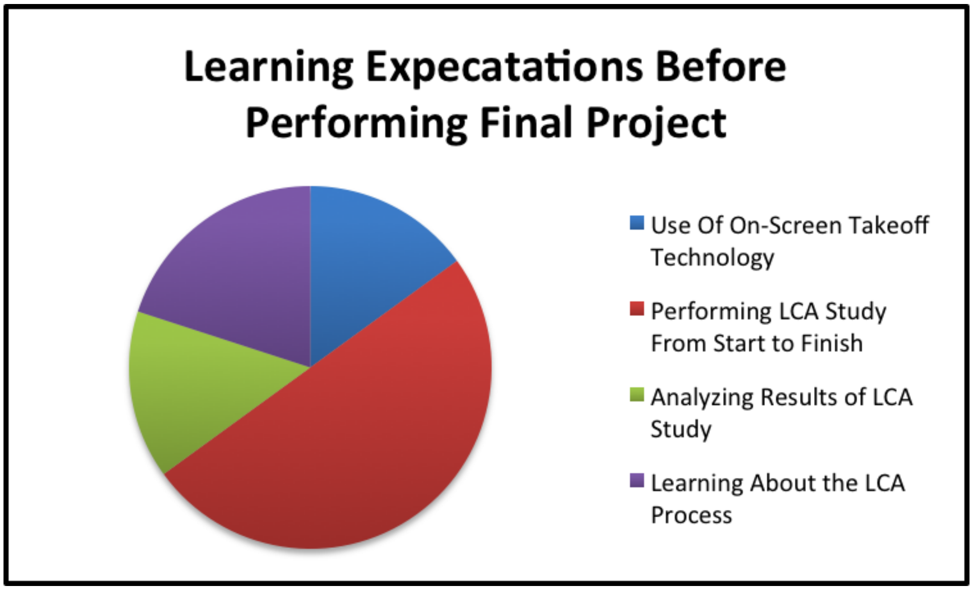



**Figure 7 - Table Displaying Learning Expectations Before Performing Final Project**

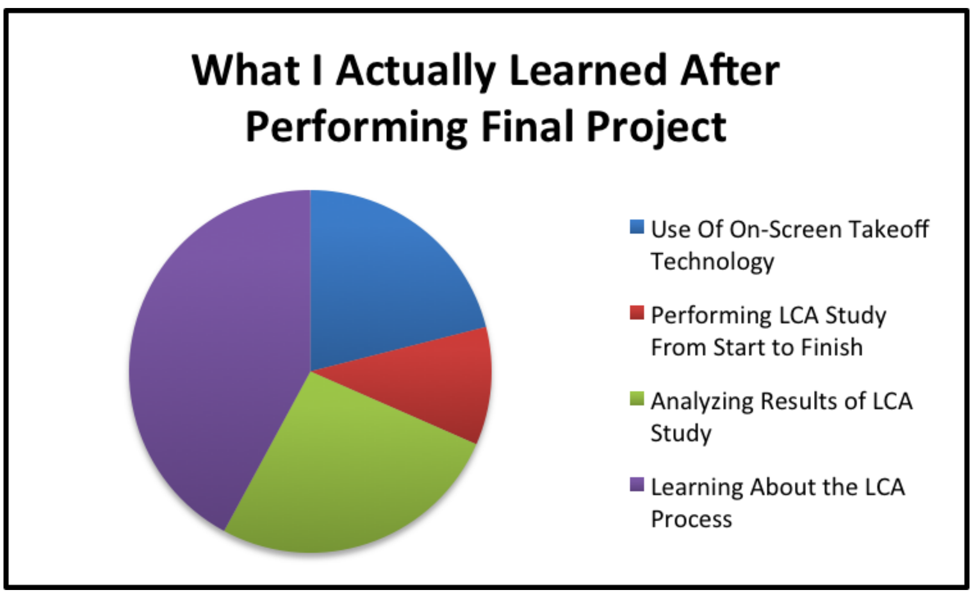



**Figure 8 - Table Displaying Actual Learning After Performing Project**

## 10.4 CEAB Graduate Attributes Demonstrated

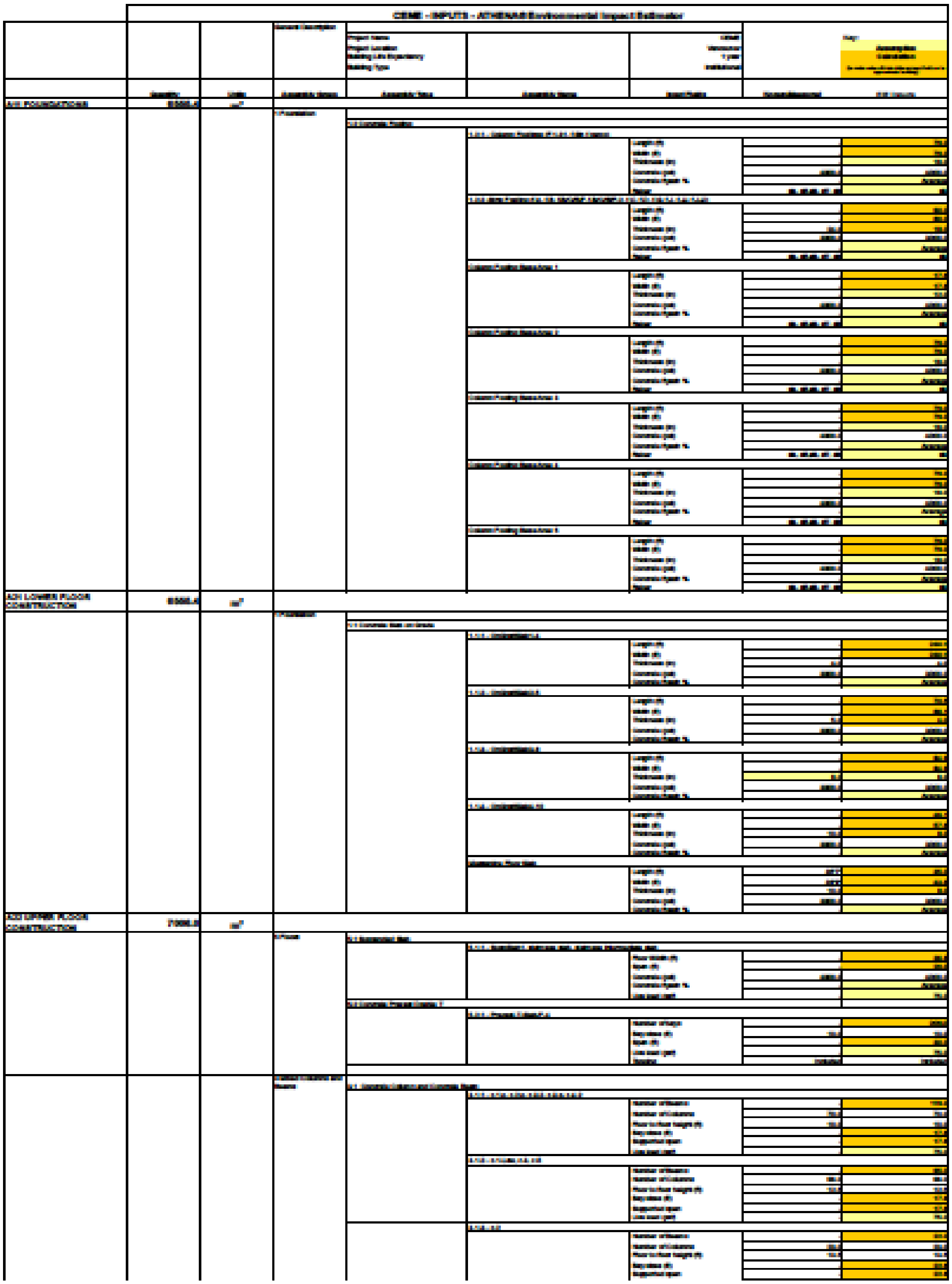
The table below illustrates on which of the 12 CEAB Graduate attributes I believe I demonstrated in this project:

| Attribute Name | Description | Select the content code most appropriate for each attribute from the dropdown menue | Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your 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 = applied | I applied basic building knowledge on how to read construction plans when working on this project. I expanded on my previous skills as I spent hours pouring over the CEME drawings. |
| 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. | A = applied | I had to use problem analysis to work out how to use the two new different softwares introduced in this course: The Onscreen Takeoff Software and the Athena Impact Estimator. I have never used these programs before, so I had to use problems solving to learn how to upload files, and manipulat the previous data in the report. |
| 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. | IDA = introduced, developed & applied | The final project highly focused on an investigation of a previous student's LCA of CEME. I had to interpret their previous work on the impact estimator in Athena, as well as interpret their data to ensure their assumptions were correct and that his previous work was accurate. |
| 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 = not applicable | Designing solutions was not applicable in this course as our project revolved around taking a previous model and manipulating it. |
| 5 Use for 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. | IDA = introduced, developed & applied | The Athena Impact Estimator Tool as well as the On Screen Takeoff was introduced, developed and applied for this project. |
| 6 Individual and Team Work | An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting. | IDA = introduced, developed & applied | I had to use teamwork throughout the course when working on group assignments and quizzes. This previous knowledge from the team activities was helpful when I was writing the final report, escecially the final Annexes. |
| 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. | A = applied | I had to use communication with my fellow classmates to discuss the final project if I was unsure of how to proceed. Furthermore I used communication when I contacted various individuals who worked for UBC when searching for more information about the CEME building. |
| 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 = applied | I believe I had to apply professionalism when meeting with the professor to discuss the final project. |
| 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. | IDA = introduced, developed & applied | The final project allowed me to see how beneficial LCA can be in practice to analyze all impacts the construction of a building could have on the environment. As engineers, we are socially responsible to know the impacts of our jobs. Life cycle analysis helped me understand the entire construction process from product manufacturing to the end of life stages of a building. This concept was reiterated throughout the final project as a major theme. I definitely applied this skill. |
| 10 Ethics and Equity | An ability to apply professional ethics, accountability, and equity. | N/A = not applicable | Not Applicable. |
| 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. | IA = introduced & applied | Life Cycle Costing was introduced in the course. In order to find our building's cost in 2013 dollars, we applied basic economics, more specifically, the concept of Net Present Value. |
| 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. | ID = introduced & developed | As LCA is a relatively new concept in building design and analysis, in the long term I see knowing how an LCA works to be beneficial in the workforce. By having an introduction to Athena, as it is continually updated, I will have a basis of knowledge in the software and can expand it as technology advances. |

**Table 20 - CEAB Graduate Elements Table**

# 11.0 Annex D – Impact Estimator Inputs and Assumptions

The inputs and assumptions are illustrated below. The excel file can be found in Dropbox.



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| A20 ROOF CONSTRUCTION | [illegible] | m² | | | | | | |
| | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| A30 WALLS BELOW GRADE | [illegible] | m² | | | | | | |
| | | | | | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

## CEME - ASSUMPTIONS - ATHENA® Environmental Impact Estimator

| General Description | | | |
|---|---|---|---|
| | Project Name<br>Project Location<br>Building Life Expectancy<br>Building Type<br>Operating Energy Consumption | | CEME<br>Vancouver<br>1 year<br>Institutional<br>-TBA- |
| **Assembly Group** | **Assembly Type** | **Assembly Name** | **Assumptions and Calculations** |
| **A11 Foundations** | | | |
| | 1.2 Concrete Footing | | |
| | | 1.2.1 - Column Footings (F-1-21, 1.98: 1.gamp) | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>length = width = sqrt (6241) = 79<br>Thickness approximated as 18inches based on common thickness |
| | | 1.2.2 -Strip Footing (1.A, 1.B, 1.BC/3/F, 1.BC/3/F-3, 1.C, 1.D, 1.G, 1.J, 1.JJ, 1.JJJ) | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>Length = sqrt (area) = 60<br>Width = length /18in * 24in<br>Adjustments to the dimensions were necessary to make them fit the inputs into the Impact Estimator - the same |
| | | Column Footing Base Area 1 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>length = width = sqrt (5x5x5x5x1) = 17.6 |
| | | | Thickness assumed to be 1ft. |
| | | Column Footing Base Area 2 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>length = width = sqrt (18x3x2x1) = 10.4 |
| | | | Thickness assumed to be 1ft. |
| | | Column Footing Base Area 3 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>length = width = sqrt (3x3x1x21) = 13.8 |
| | | | Thickness assumed to be 1ft. |
| | | Column Footing Base Area 4 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>length = width = sqrt (3x3x1x26) = 15.3 |
| | | | Thickness assumed to be 1ft. |
| | | Column Footing Base Area 5 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>length = width = sqrt (3x3x1x17) =10.1 |
| | | | Thickness assumed to be 1ft. |
| **A21 Lower Floor Construction** | | | |
| | 1.1 Concrete Slab on Grade | | |
| | | 1.1.1 - OnGradSlab1-4 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Length & Width = Sqrt (Area) = Sqrt (52946.01) = 230.1ft |
| | | 1.1.2 - OnGradSlab2-5 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Length = Sqrt (area) = sqrt (4969) = 70.5<br>Width = 70.5 / new width x old with = 70.5/4*5 = 88.1 |
| | | 1.1.3 - OnGradSlab3-8 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Length = width = sqrt (area) =sqrt (7215) = 84.9 |
| | | 1.1.4 - OnGradSlab4-10 | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Length = sqrt (area) = SQRT(2137) = 46.1<br>Width = length / 8 * 10 = 57.6 |
| | | Mezzanine Floor Slab | |
| | | | Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Length - 357" x 389" |
| **A22 Upper Floor Construction** | | | |
| | 5.1 Suspended Slab | | |
| | | 5.1.1 - SuspSlab1, staircase slab, staircase intermediate slab | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Span chosen to be 20ft, width = area / span<br>736 / 20 = 36.8 |
| | 5.2 Concrete Precast Double T | | |
| | | 5.2.1 - Precast-T-Slab-F-4 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Span chosen to be 30ft, number of bays = area / span / bay size<br>62700 / 30 / 10 = 209 |
| | 3.1 Concrete Column and Concrete Beam | | |
| | | 3.1.1 - c.1.p, c.2.p, c.3.2, c.3.p, c.4.2 | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Number of beams = number of columns -1 = 120 - 1 = 119<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (309.8) = 17.6 |
| | | 3.1.2 - c.1-Low, c.3, c.5 | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Number of beams = number of columns -1 = 66 - 1 = 65<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (316.8) = 17.8 |
| | | 3.1.3 - c.2 | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Number of beams = number of columns -1 = 23 - 1 = 22<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (510.8) = 22.6 |

| | | | |
|---|---|---|---|
| | | 3.1.4 - c.2.b | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Number of beams = number of columns -1 = 10 - 1 = 9<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (497.3) = 22.3 |
| | | 3.1.5 - c.1-High | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Number of beams = number of columns -1 = 31 - 1 = 30<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (368.8) = 19.2 |
| | 3.2 Concrete Column and No Beam | | |
| | | 3.2.1 - c.2.2, c.5.p | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (295) = 17.2 |
| | | 3.2.2 - c.4 | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Span = Bay size = sqrt (supported area)<br>Span = Bay size = sqrt (510) = 22.6 |
| **A23 Roof Construction** | | | |
| 4 Roofs | 4.1 Open Web Steel Joist | | |
| | | 4.1.1 - Steel-Joist | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Roof consists of 1 1/2" built up asphalt roof, but not specified. Approximated by "Extruded Polystyrene, Glass<br>Roof is topped with asphalt but not specified. Approximated with Impact Estimator's "Roofing Asphalt"<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial<br>Roof width assumed 30 to fit input parameter, span = area / roof with<br>40140 / 30 = 1338 |
| | | 4.1.2 - Steel-Joist-Pent | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial<br>Roof width assumed to be 15ft, span = area / width<br>6039 / 15 = 402.6 |
| | 4.2 Concrete Precast Double T | | |
| | | 4.2.1 - Precast-T-slab-R-4 | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Roof consists of 1 1/2" built up asphalt roof, but not specified. Approximated by "Extruded Polystyrene, Glass<br>Roof is topped with asphalt but not specified. Approximated with Impact Estimator's "Roofing Asphalt"<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial<br>Span chosen to be 24ft, number of bays = area / span / bay size<br>14 = 3360 / 24 / 10 |
| | | A23 Roof Construction-Steel-Joist-Pent-1 | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Roof consists of 1 1/2" built up asphalt roof, but not specified. Approximated by "Extruded Polystyrene, Glass Felt"<br>Roof is topped with asphalt but not specified. Approximated with Impact Estimator's "Roofing Asphalt"<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial steel roof system.<br>All previous penthouse roof assumptions still apply. Only dimensions of the roof were incorrect and modified as per "Model Improvements" tab. |
| | | A23 Roof Construction-Steel-Joist-Pent-2 | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Roof consists of 1 1/2" built up asphalt roof, but not specified. Approximated by "Extruded Polystyrene, Glass<br>Roof is topped with asphalt but not specified. Approximated with Impact Estimator's "Roofing Asphalt"<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial<br>All previous penthouse roof assumptions still apply. Only dimensions of the roof were incorrect and modified as per "Model Improvements" tab. |
| | | A23 Roof Construction-Steel-Joist-Pent-3&4 | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Roof consists of 1 1/2" built up asphalt roof, but not specified. Approximated by "Extruded Polystyrene, Glass<br>Roof is topped with asphalt but not specified. Approximated with Impact Estimator's "Roofing Asphalt"<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial<br>All previous penthouse roof assumptions still apply. Only dimensions of the roof were incorrect and modified as per "Model Improvements" tab. |
| | | A23 Roof Construction-Steel-Joist-Pent-5 | |
| | | | Drawings contain virtually no specifics on the Open Web Steel Joist roofing systems.<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Roof consists of 1 1/2" built up asphalt roof, but not specified. Approximated by "Extruded Polystyrene, Glass<br>Roof is topped with asphalt but not specified. Approximated with Impact Estimator's "Roofing Asphalt"<br>Above Open Web Steel Joist is corrugated steel that the drawings do not detail - assumed to be a commercial<br>All previous penthouse roof assumptions still apply. Only dimensions of the roof were incorrect and modified as per "Model Improvements" tab. |
| | 3.1 Concrete Column and Concrete | | |
| | | 3.1.1 - c.1.p, c.2.p, c.3.2, c.3.p, c.4.2 | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Number of beams = number of columns -1 = 120 - 1 = 119<br>Supported area and number of columns changed to accommodate CIQS Sorting |
| | 3.2 Concrete Column and No Beam | | |
| | | 3.2.1 - c.2.2, c.5.p | |
| | | | Column Bay and Span determined by taking floor area that columns were in, divided by the number of columns,<br>Live load not specified in drawings. Assumed 75 psf based on other institutional building in vicinity of CEME<br>Supported area and number of columns changed to accommodate CIQS Sorting |
| **A31 Walls Below Grade** | | | |
| | Basement Walls | | |
| | | Area 2 Basement Walls | Assume basement walls are 7'0" - As per difference in elevations<br>Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen<br>Assume thickness is 8" when in reality it is 6" |
| | | Area 4 Basement Walls | Assume basement walls are 7'0" - As per difference in elevations<br>Fly ash concentration was not detailed in drawings, therefore the flyash percentage was assumed to be average.<br>Consist of a variety of rebar. The most common grade was chosen |
| **A32 Walls Above Grade** | | | |
| | 2.1 Concrete Tilt-up | | |

| | |
|---|---|
| 2.1.1 - ws.1-0400-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 109 / 5.5 * 6 = 118.9 |
| 2.1.2 - ws.1-0600-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 110 / 5.5 * 6 = 120 |
| 2.1.3 - ws.1-0700-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 200 / 5.5 * 6 = 218.2 |
| 2.1.4 - ws.1-0707-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 279 / 5.5 * 6 = 304.4 |
| 2.1.5 - ws.1-0900-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 202 / 5.5 * 6 = 220.4 |
| 2.1.6 - ws.1-1000-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 73 / 5.5 * 6 =79.6 |
| 2.1.7 - ws.1-1400-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 70 / 5.5 * 6 = 76.4 |
| 2.1.8 - ws.1-1407-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 477 / 5.5 * 6 = 520.4 |
| 2.1.9 - ws.1-1500-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 71 / 5.5 * 6 = 77.5 |
| 2.1.10 - ws.1-1600-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 426 / 5.5 * 6 = 464.7 |
| 2.1.11 - ws.1-1606-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 42 / 5.5 * 6 = 45.8 |
| 2.1.12 - ws.1-1700-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 283 / 5.5 * 6 = 308.7 |
| 2.1.13 - ws.1-1800-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 389 / 5.5 * 6 = 424.4 |
| 2.1.14 - ws.1-1900-6 | |
| | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation |

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| | | | Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 344 / 5.5 * 6 = 375.3 |
| | | 2.1.15 - we.1-2100-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 273 / 5.5 * 6 = 297.8 |
| | 2.2 Concrete Block Wall | | |
| | | 2.2.1 - we.2-1500-6 | |
| | | | The Impact Estimator assumes 200mm thick block. Length of 6" thick block wall multiplied by 0.762 to achieve<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>244.6 = 321 * 0.762 |
| | 2.3 Cast-in-Place | | |
| | | 2.3.1 - we.3-1300-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = actual length / EIE thickness * actual thickness<br>69.8 = 93 / 8 * 6 |
| | | 2.3.2 - we.3-1600-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>EIE Length = actual length / EIE thickness * actual thickness<br>84.8 = 113 / 8 * 6 |
| | | 2.3.3 - we.3-1700-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing"<br>EIE Length = actual length / EIE thickness * actual thickness<br>30.8 = 41 / 8 * 6 |
| | | 2.3.4 - we.3-1800-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = actual length / EIE thickness * actual thickness<br>45 = 60 / 8 * 6 |
| | 2.5 Steel Stud | | |
| | | 2.5.1 - we.9-1200-4 | |
| | | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>Stud Weight not specified in the drawings and assumed to be Light.<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing" |
| | | 2.5.2 - we.9-1300-4 - NB | |
| | | | Stud Weight not specified in the drawings and assumed to be Light.<br>Glazing not specified for windows in drawing and assumed to be "Standard Glazing" |
| | | 2.5.3 - we.9-2000-4 | |
| | | | Stud Weight not specified in the drawings and assumed to be Light. |
| 6 Extra Basic Materials | 6.1 Gypsum Board | | |
| | | 6.1.1 - Win Asbestos | |
| | | | Many window frames in the building contain panels that are steel stud walls with solid insulation and backing |
| | 6.2 Insulation | | |
| | | 6.2.1 - Win Asbestos | |
| | | | Many window frames in the building contain panels that are steel stud walls with solid insulation and backing board forced with asbestos. This was approximated by finding the materials in a square foot wall with the steel studs, extruded polystyrene insulation, and OSB. The Impact Estimator can not model asbestos. See end of Assumption table for calculations |
| | 6.3 Steel | | |
| | | 6.3.1 - Win Asbestos | |
| | | | Many window frames in the building contain panels that are steel stud walls with solid insulation and backing |
| | | 6.3.2 - Win Asbestos | |
| | | | Many window frames in the building contain panels that are steel stud walls with solid insulation and backing |
| | 6.4 Wood | | |
| | | 6.4.1 - Win Asbestos | |
| | | | Many window frames in the building contain panels that are steel stud walls with solid insulation and backing |
| **B11 Partitions** | | | |
| | 2.1 Concrete Tilt-up | | |
| | | 2.1.16 - wi.1-1300-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 11 / 5.5 * 6 = 12 |
| | | 2.1.17 - wi.1-1500-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 73 / 5.5 * 6 = 77.9 |
| | | 2.1.18 - wi.1-1506-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 222 / 5.5 * 6 = 242.2 |
| | | 2.1.19 - wi.1-1700-6 | |
| | | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #4<br>Dimensions were adjusted to account for limited thickness options<br>Type of "1in Rigid Insulation" not specified in drawings and assumed to be "Polystyrene Extruded" insulation<br>EIE Length = Length / EIE Thickness * Actual Thickness<br>EIE Length = 19 / 5.5 * 6 = 20.7 |
| | 2.2 Concrete Block Wall | | |

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| | 2.2.2 - wl.2-0900-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>95.3 = 125 * 0.762 |
| | 2.2.3 - wl.2-0900-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>Walls assumed to be 9ft tall based on other walls the area<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>261.4 = 343 * 0.762 |
| | 2.2.4 - wl.2-1000-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>35.8 = 47 * 0.762 |
| | 2.2.5 - wl.2-1000-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 1.016 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 1.016 (200mm/8in)<br>9.1 = 9 * 1.016 |
| | 2.2.6 - wl.2-1300-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 1.016 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 1.016 (200mm/8in)<br>24.4 = 24 * 1.016 |
| | 2.2.7 - wl.2-1200-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>461 = 605 * 0.762 |
| | 2.2.8 - wl.2-1500-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>453.4 =595 * 0.762 |
| | 2.2.9 - wl.2-1800-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>147.8 = 194 * 0.762 |
| | 2.2.10 - wl.2-1800-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 0.762 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 0.762 (200mm/8in)<br>673.6 = 884 * 0.762 |
| | 2.2.11 - wl.5-1000-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 1.016 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 1.016 (200mm/8in)<br>24.4 = 24 * 1.016 |
| | 2.2.12 - wl.5-1300-6 | |
| | | The Impact Estimator assumes 200mm thick block. Length of 8" thick block wall multiplied by 1.016 to achieve<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = Actual Length * 1.016 (200mm/8in)<br>159.7 =157 * 1.016 |
| 2.3 Cast-in-Place | | |
| | 2.3.5 - wl.3-1300-6 | |
| | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = actual length / EIE thickness * actual thickness<br>69 = 92 / 8 * 6 |
| | 2.3.6 - wl.3-1300-6 | |
| | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for |
| | 2.3.7 - wl.3-1600-6 | |
| | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = actual length / EIE thickness * actual thickness<br>35.3 = 47 / 8 * 6 |
| | 2.3.8 - wl.3-1700-6 | |
| | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = actual length / EIE thickness * actual thickness<br>30 = 40 / 8 * 6 |
| | 2.3.9 - wl.3-1800-6 | |
| | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>EIE Length = actual length / EIE thickness * actual thickness<br>105 = 140 / 8 * 6 |
| | 2.3.10 - wl.3-1800-6 | |
| | | Concrete flyash percentage not specified and assumed to be average<br>Rebar not specified in drawings and assumed to be #5<br>Dimensions were adjusted to account for limited thickness options<br>Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for |
| 2.4 Wood Stud | | |
| | 2.4.1 - wl.4-0700-6 | |
| | | None |
| | 2.4.2 - wl.4-0900-6 | |
| | | None |
| | 2.4.3 - wl.4-1200-6 | |
| | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for |
| | 2.4.4 - wl.4-1300-6 | |
| | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for |
| | 2.4.5 - wl.4-1500-6 | |
| | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for |
| | 2.4.6 - wl.4-1800-6 | |
| | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for |
| | 2.4.8 - wl.4-500-6 | |

| | | | |
|---|---|---|---|
| | | | None |
| | | 2.4.9 - wl.7-1300-6 | |
| | | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>"Backing Board" not specified and assumed to be Oriented Strand Board<br>Fiberglass insulation type not specified but based on usage and thickness assumed to be Batt insulation |
| | | 2.4.10 - wl.7-1500-6 | |
| | | | "Backing Board" not specified and assumed to be Oriented Strand Board<br>Fiberglass insulation type not specified but based on usage and thickness assumed to be Batt insulation |
| | | 2.4.11 - wl.7-1800-6 | |
| | | | "Backing Board" not specified and assumed to be Oriented Strand Board<br>Fiberglass insulation type not specified but based on usage and thickness assumed to be Batt insulation |
| | | 2.4.12 - wl.8-1300-6 | |
| | | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>"Backing Board" not specified and assumed to be Oriented Strand Board<br>Fiberglass insulation type not specified but based on usage and thickness assumed to be Batt insulation |
| | 2.5 Steel Stud | | |
| | | 2.5.4 - wl.9-1500-4 | |
| | | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>Stud Weight not specified in the drawings and assumed to be Light. |
| | | 2.5.5 - wl.10-1000-4 | |
| | | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>Stud Weight not specified in the drawings and assumed to be Light.<br>Additional layer clearly visible on drawings but not specified. Assumed to be an additional 1/2" Drywall based on |
| | | 2.5.6 - wl.10-1300-4 | |
| | | | Door type not specified in the drawings and assumed to be "Steel Exterior" for exterior walls, "Steel Interior" for<br>Stud Weight not specified in the drawings and assumed to be Light.<br>Additional layer clearly visible on drawings but not specified. Assumed to be an additional 1/2" Drywall based on thickness in drawing |

Total Asbestos 1578 SF

| 1 sq.ft of Asbestos Walls | | | Totals | |
|---|---|---|---|---|
| Material | Quantity | Unit | Quantity | Unit |
| 1/2" Regular Gypsum Board | 0.1022 | m2 | 161.2716 | m2 |
| Extruded Polystyrene | 0.145 | m2 (25mm) | 228.81 | m2 (25mm) |
| Galvanized Studs | 0.0013 | Tonnes | 2.0514 | Tonnes |
| Oriented Strand Board | 0.1297 | m2 (9mm) | 204.6666 | m2 (9mm) |
| Screws Nuts & Bolts | 0.0002 | Tonnes | 0.3156 | Tonnes |