UBC Civil 498C
Chemical and Biological Building
Life Cycle Assessment

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CIVL 498C

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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.

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THE UNIVERSITY OF BRITISH COLUMBIA

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Executive Summary

The whole building life cycle assessment of University of British Columbia Chemical and Biological Engineering building is a part of continuing developing study. The scope for this particular report is emphasizing on the product and construction stage of the building life. To achieve this, OnCenter's OnScreen TakeOff and Athena Sustainable Material Institute's Impact Estimator were used to model the building and calculate its associated impact and consumption. The output result of the Athena IE software then used to develop a benchmark comparison with other UBC building LCA studies that completed by other members of class. The comparison of whole CHBE building analysis shows promising result, but the analysis for each building elements contain bigger discrepancy compared with class average result. In order to apply LCA study result to real life decision-making, further developing of the module to include the usage stage and end of life to fulfill the objective of life cycle assessment is strongly recommended.

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1.0 General Information on the Assessment

1.1 Purpose of the Assessment

Building life cycle assessment is a technique developed to include all the stages of building life from raw material accusation, material processing, manufacture, transportation and distribution, operation, and demolition and recycle in the evaluation of environmental impacts. The use of LCA could potentially mitigate some of the narrow outlooks of environmental concerns that could include in other traditional assessment methods.

In this particular report, the whole building life cycle assessment analysis is conducted for Chemical and Biological Building at the University of British Columbia as an experimental study to determine the potential effects of endpoints to its impact categories. "Cradle to Gate" method, a partial building life cycle that only emphasizes the production and construction stage of the building life cycle as well as the transportation effect throughout, is used in the project.

The result of the assessment will also be used as comparative analysis with other UBC buildings that has same goal and scope that are completed by other members of the class. The material inventory and environmental impact references for the UBC CHBE building will be established to assist the potential future performance upgrade regarding structure design, material selection. These potential applications could be further interpreted to support decision-making and sustainable policy development for UBC's infrastructures' construction, renovation, rehabilitation, and demolition.

This result of the study would not only benefit the internal organizations such as UBC board of governors, sustainability development office, who are in charge of sustainable development policy making, but also would benefit external organizations such as municipal government, engineers, environmentalists, life cycle practitioners as useful life cycle information database and decision making aid.

1.2 Identification of Building

UBC Chemical and Biological Engineering Building is located at 2360 East Mall, Vancouver BC. The building serves multipurpose such as lecture hall, computer and research laboratories, workshop, and office spaces, meeting room and seminar room. The building construction was completed at September 2005 and the cost of the building at that time was $38 million funded from a number of sources.[1]

Figure 1 below show the plan view of ground floor of CHBE building. At the main section of CHBE build, there are seven floors. And there are two floors at north end. There also a outdoor storage area available which located between the east and west section. [2]

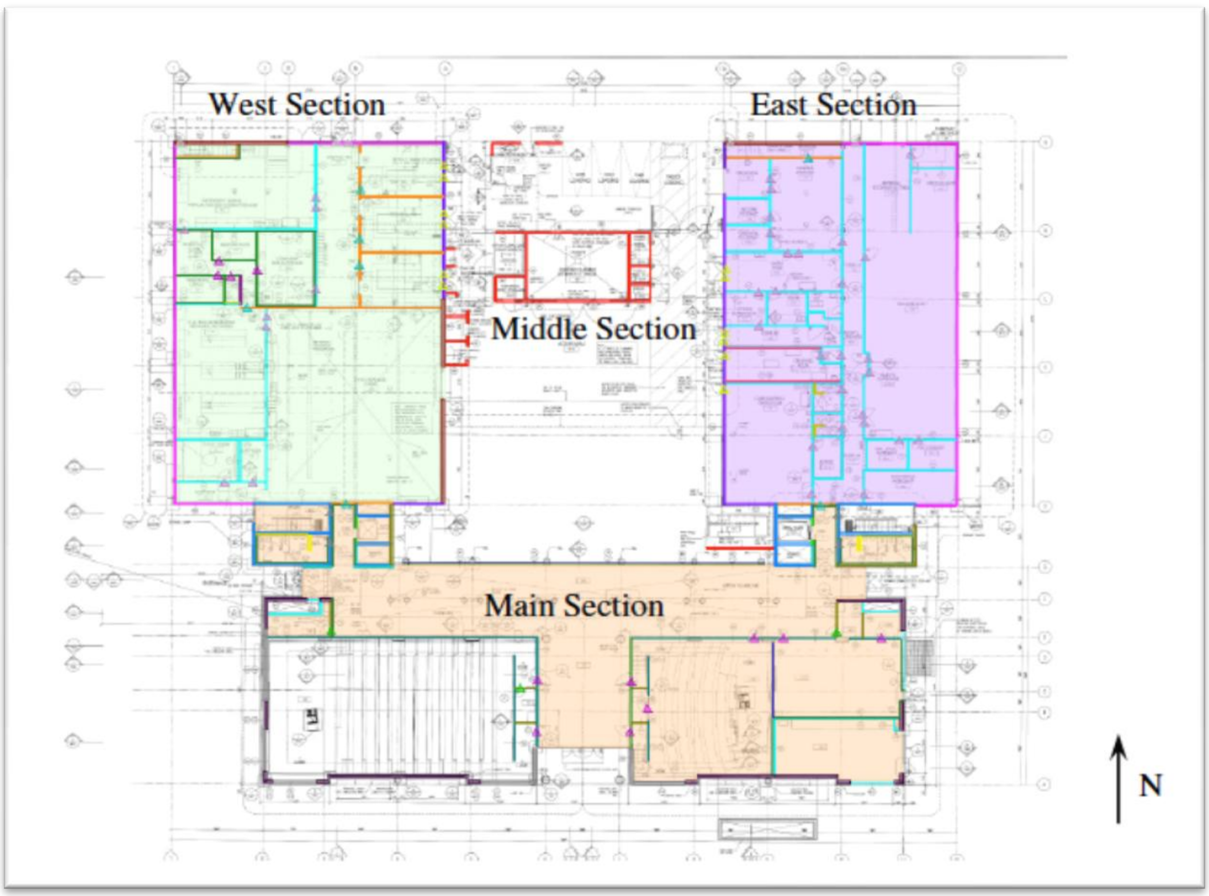

Figure 1 Ground level floor plan

[1] (Watkinson, 2006)
[2] (Whole Building Life Cycle Assessment Chemical and Biological Engineering Building, 2010)

1.3 Other Assessment Information

The table below is a summary of general assessment information. This help better to understand the system of the study. The project was complete reference to life cycle assessment on CHBE building completed on year 2010. However the name of the author was undetermined.

Table 1 Information on Assessment

Client for Assessment	**Completed as coursework in CIVL 498C technical elective course in Civil Engineering at the University of British Columbia.**
Name and qualification of the assessor	Rongbing Zhang, B_Apsc Civil Engineering Student; Previous study completed on 2010 (Author unknown)
Impact Assessment method	On Screen TakeOff_Version 3.9.0.6 "Cradle to Gate" method Athena impact estimator for building_Version4.2.0208
Point of Assessment	8 years.
Period of Validity	5 years.
Date of Assessment	Completed in December 2013.
Verifier	Coursework, study not verified.

2.0 General Information on the Assessment

2.1 Functional Equivalent

Functional units are performance characteristic of the product system being studied that will be used as reference unit to normalize the result of the study.[3] Functional unit is the basis for analysis in LCA study; therefore, clearly identify the fictional unit will provide more adequate results for potential intend application of the UBC whole building LCA study.

Table 2 below provides a summary of fictional equivalents for UBC CHBE building LCA study. The information was obtained from UBC Properties Trust. [4]

Table 2 Functional Equivalent Definitions

Aspect of Object of Assessment	Description
Building Type	Academic Institutional
Technical and functional requirements	Sustainability Rating: Silver (Equivalent) Initiative: to increase the enrollment of graduate students in the engineering and science disciplines. Two major components: replacement for previous chemical and biological department; new faculty: clean energy research center.
Pattern of use	Three lecture halls consist 60,90,200 occupants; computer and research laboratories; office space; design workshop.
Required service life	60 years or longer.

[3] (Canada Standard Association, 2006)
[4] (UBC Properties Trust, 2009)

2.2 Reference Study Period

According to EN15978, the default study period for LCA should be the required service life of the building. The reason to use service life as study period is LCA emphasize the whole life cycle of the building from material production to demolition. In order to fully study the whole process of building cycle, use of service life as study period is required. However, in this particular study developed for civil 498C class, the "cradle to gate" method is used to develop the LCA study. The system boundary for this method is only focus on the partial life stage of the building that only includes the module A in EN15978 standard. Figure 3 below indicate the general system boundary for LCA study, but modules B, C and D are excluded for this project. [5]

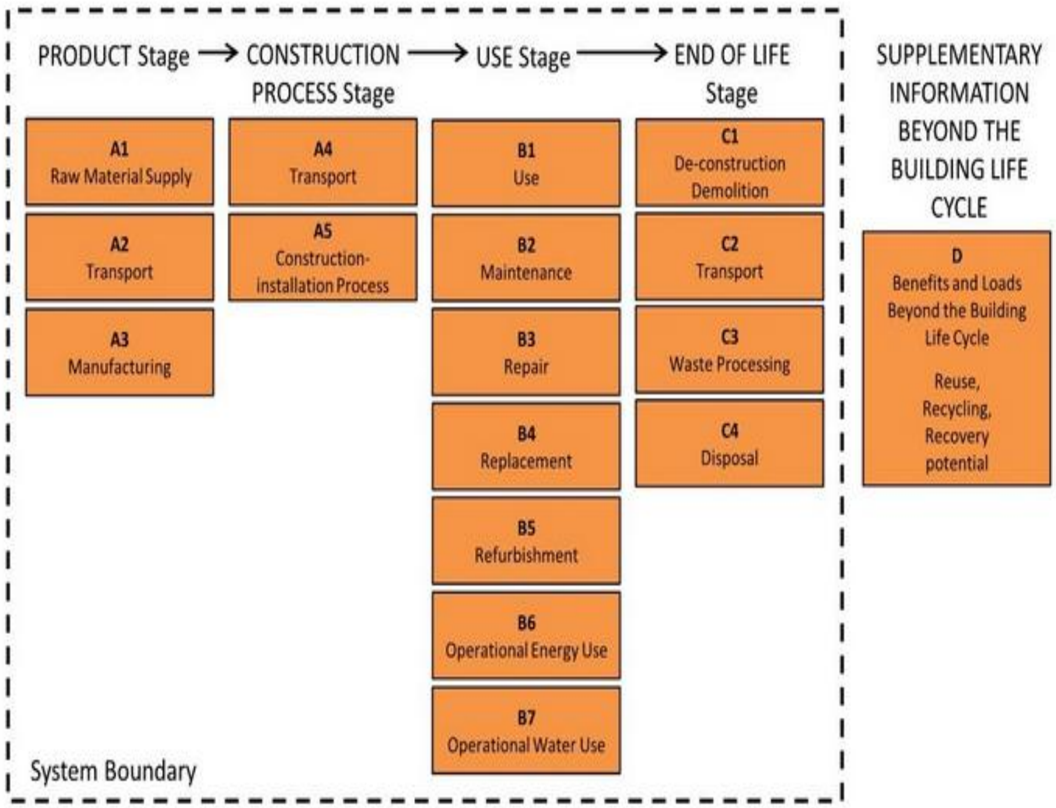

Figure 2 Building LCA System Boundaries According to EN 15804/15978

[5] (Coldstream Consulting, 2013)

2.3 Object of Assessment Scope

The system boundary for UBC CHBE building LCA study is applying a cradle- to-gate scope that include only partial of the building life cycle from raw material extraction, production of construction material, construction of the building structure and envelope, and also associate the environmental impact due to transportation and distribution of the material.

Due to the limited timeframe of the class as well as the data availability, some deviations were made from EN15978. In EN 15978, the object of the assessment should include the building, from its foundations to the external works enclosed within the area of the building's site, over the reference study period. [6] For this project, cradle-to-gate scope was employed rather than analysis entire life cycle of CHBE building. And the study period for the building was modified to be 1 year in Athena impact estimator (IE) when exporting result to better qualify cradle-to-gate scope. This results in maintenance, operating energy and end-of –life stags of the building's lifecycle being left out side the scope of assessment.

The input document was sorted based on Canadian Institution of Quantity Surveyors (CIQS) level 3 elements with some adjustment to suit the scope of this project. The assemblies of the building include footings, slab on grade, column and beams, floors, stairs, walls, roofs, interior doors and windows opening and their associated envelope. Some of the components in CIQS level 3 elements such as shoring, finishes, exterior doors and screens, and interior door frame and hardware were excluded in the object of assessment due to limitations of available data and the IE software, as well as to minimize the uncertainty of the model.

[6] (Coldstream Consulting, 2013)

Table 3 below summarize the according to CIQS level 3 elements and some adjustment were made to fit this particular project. The quantity takeoffs for each element were calculated using combination of CHBE building architectural drawings and OnScreen TakeOff file provided from 2010 study. The measurement for both A21 foundation and A 22 lowest floor construction are the sum of total area of the slab-on-grade. A22 upper floor construction is measured using the sum of the total area of all upper floors. Sum of total area of the roofs measured from outside face of exterior wall was used for A23 roof construction quantity measurement. A31 walls below grade and A32 walls above grade were calculated using the sum of total surface area of exterior wall above and below grade. Finally, B11 partition section is measurement of sum of the total surface area of interior walls.

Table 3 Assessment Scope and Building Definition

CIVL 498C Level 3 Elements	Description	Quantity
A11 Foundations	Wall and column footings	3192.25 m2
A21 Lowest Floor Construction	Slab on grade	3192.25 m2
A22 Upper Floor Construction	All columns and beams supporting floors, floors, and stairs structure	7596.56 m2
A23 Roof Construction	Roof structures and all columns and beams supporting the roof	3563.54 m2
A31 Walls Below Grade	External walls directly connect to slab on grade	832.04 m2
A32 Walls Above Grade	External walls above ground floor which include curtain walls, walls cast in place and concrete block	3311.1 m2
B11 Partitions	Interior walls, door opening, window opening and envelope	1044.16 m2

3.0 Statement of Boundaries and Scenarios Used in the Assessment

3.1 System Boundary

According to ISO14040: 2006, system boundary is defined as set of criteria specifying which unit processes, smallest element considered in the life cycle inventory analysis for which input and output data are quantified, are part of a product system, and which impacts created by the product system are considered.[7]

The system boundary in this project is emphasizing the product stage and construction stage of CHBE building life cycle. The processes include the initial raw material acquisition, transportation of the raw materials to manufacture, manufacture of the construction materials, distribution of the construction materials to construction and finally the construction installation. The downstream of the construction stage is the use/operation stage of the building, and finally lead to the end life of the building include demolition, transportation of the waste material, waste processing, and disposal. However, the use stage and end life stage is not included in the objective of this study. Figure 2 inserted in the previous give a general perspective of modular information for the different stages of the building assessment based on default EN 15798 LCA standard.

Athena sustainable material institute's impact estimator for building _Version4.2.0208 was used for evaluation of impact categories of product stage and construction process stage. The environmental impacts on following impact categories are addressed: fossil fuel depletion; global warming potential; acidification and acid deposition, human health criteria (respiratory), neutrification/eutrophication of water bodies, ozone layer depletion, and smog potential.

3.2 Product Stage

The CHBE building is primarily concrete building with the some of the outer wall being veneer masonry. Concrete construction plays a major contribution to global warming potential impact that is the impact category we emphasize as a comparative assertion with other class members' UBC building LCA study. After the raw material acquisition completed, the material will be either delivered to a concrete mixing plant to produce concrete for construction and then concrete will be ship to construction site to cast

[7] (Canada Standard Association, 2006)

in place, or concrete block would be form at manufacture and concrete block will be shipped to construction site for installation.

Athena impact estimator reports the impacts due to production stage into the following process module: manufacturing and transport. In each component the life cycle stage was evaluated using seven impacts categories stated in the previous section. In LCA terminology, making and transporting of product are recognized as "embodied effect" in contrast to actual physical embodiment. Therefore, all of the extractions gained from and returned back to nature are embodied effects. Also, some production and transportation of energy itself are considered embodied effects also known as pre-combustion effects. The environmental impacts caused by product stage are measured by tracking energy use emission to air, water and land per unit of resource. Also the transportation and distribution from raw material to manufacture, and from manufacture to construction is included. In Athena inventory studies, The Impact Estimator software combines resource extraction and manufacturing into a single activity stage for results reporting purposes. Athena impact estimator is not attempt to address all land-impact measures, many of which are tracked in other environmental metrics or regulatory programs. Athena building impact estimator does not account the impact due to packaging, production of ancillary materials or pre-products, collection and transport of waste to disposal or to another production site and waste management processes during the product and construction stages. [8]

3.3 Construction Stage

The construction stage of CHBE building consist transportation from the construction material from upstream process (manufacturing gate) to construction site, and on-site construction.

Athena building impact estimator also evaluate the construction in seven impact categories and divide the stage into two process module: transport and construction installation. Onsite construction could be considered as an additional step for manufacture that individual components are installed according to form the building structure. In the Athena tools, the stage starts with the individual assemblies being transport from manufactory location. In order to account for travel distance, an average of typical transportation distance to building site within major North America cities are applied. This is an important life cycle stages that is often overlooked in life cycle assessments for

[8] (Athena Sustainable Material Insititute, 2013)

products alone. Athena software also accounts for components such as transportation of equipment to and from the site, site transformation of construction products such as concrete form-work, storage of the product – including the provision of heating, cooling, and humidity in addition to building product transportation, energy use of machines and waste generation. [9]

4.0 Environmental Data

4.1 Data sources

Life cycle inventory (LCI) analysis was complete employing Athena LCI Database for material process data, and energy combustion and pre-combustion processes for electricity generation and transportation is completed using US LCI Database.

Athena LCI Database is developed buy Athena institute by conducting life cycle research and the database has been growing and evolving ever since its first establishment. It is build from ground up using actual mill or engineer generation and are not rely on government data or trade. The databases include key building products, covering 90-95% of the structural and envelope systems applicable to typical commercial, institutional, light industrial and residential buildings. Athena institute has invested more than two million dollar on its dataset development. Research and other life cycle report has been used for database upgrade and expansion.[10]

US LCI database is used in Athena building impact estimator in addition to Athena LCI database to encounter the related regional electricity grid, thermal fuel use, transportation by various modes. US LCI database is developed and maintained by National Renewable Energy Lab (NREL). The database management was completed on periodically review of formats and protocols. Periodically review and update or replace data sets, incorporate new data from current LCA study are the method NREL used to expend and revise of the database.[11]

The LCI database for Athena impact estimator is regional sensitive due to differences in manufacturing technology, transportation and electricity grid. Also, the recycled contents are varied based on region. Those contribution factors make Athena LCI database sensitive by region.[12]

[9] (Athena Sustainable Material Insititute, 2013)
[10] (Athena Sustainable Material Institutes, 2013)
[11] (National Renewable Energy Laboratory (NREL), 2009)
[12] (Athena Sustainable Material Institutes, 2013)

4.2 Data adjustment and substitutions

Table 4 Material Types and Property Inaccuracies Table

Level 3 Element	Element and Material Modeling Review			
	Geometry Measurement (ex. height, length, thickness takeoffs for wall or material, door/window counts)		Type and Property Selection (ex. concrete strength, rebar size, roof/floor loading, etc.)	
	Description of Inaccuracy (ies)	IE Input(s) Effected	Description of Inaccuracy (ies)	IE Input(s) Effected
A11 Foundations			Unknown % flyash, assumption must be made	All the footings
A21 Lowest Floor Construction	Inconsistent area measurement for Athena and on-screen take off	SOG_450mm_basement	Concrete flyash % unknown, assumptions must be made	SOG_450mm_basement
A22 Upper Floor Construction	Inconsistent inputs between excel and Athena for floor suspended slab	Floor_concretet suspended slab_200mm	Inconsistent input for concrete strength	Floor_concretet suspended slab_200mm
A23 Roof Construction	Incorrect excel input for roof length and width	5.2.1 Roof_OWSJ_East Section	Many materials' information were unknown, some assumption must be made	Mostly Roof_ConcreteSuspendedSlab_Main Section_200mm
A31 Walls Below Grade			Air/vapor barrier materials were unknown	Wall_Cast-in-Place_W4A and W4B Wall_ConcreteBlock_W9
A32 Walls Above Grade	Inconsistent number of winders and total window area for IE input and Athena	2.1.2 Wall_Cast-in-Place_W1C	Many materials' information were unknown, some assumption must be made	Many components within the walls above grade elements
B11 Partitions			Door types are unknown	Concrete block wall and wall cast in place

Table 4 above was completed for stage 3 of CHBE building LCA study. The following improvement strategies were applied to improve the data accuracy:

- For lowest floor construction area was recalculated for inconsistent measurement on excel input and Athena IE input, and inaccurate excel input was corrected.
- Inconsistent input for roof construction was fixed and excels value was modified.
- Inaccurate input value in excel was corrected after to unify the number and area of the window.
- Some of the material data accuracy improvement strategies are suggested such as improvement on Athena LCI database and site visit to collect information.

However, after the above improvement is completed, there is no significant improvement IE model since the majority of the inaccuracy mentioned above were from excel input, and it has no impact on Athena impact result.

4.3 Data Quality

There five types of uncertainties in LCA study were described in Civil 498 class which are the following: database, model, temporal, spatial and variability between sources.

Data uncertainty could due to collection/allocation method used to generate data, availability or accuracy of the LCI database, uncertainty of service life of product, and differences in travel potential. Data uncertainty could impact both LCI and LCA study.

Modeling uncertainty could be embedded in difference between linear and nonlinear modeling, linear the assessment result could affect by unknown potential effect of characterization factor. Some of the model uncertainty could brought up over simplify the model since there may be unknown interaction between building parameters.

Temporal uncertainty is occurred based on time difference such as emission rate varies in different year, or data vintage. The impact result could be affected due to different interpretation over time. Since CHBE building was built at fairly recent year, the uncertainty due to temporal is very limited.

Spatial uncertainty is due to difference in regions. The factories located at different could have unlike production standard for material. Also, different region could potentially have varied sensitivity towards different environmental impact. The Athena LCI and US LCI database is develop to suit North American standard. So, the uncertainty in CHBE building LCI data source is mitigated.

Variability between data sources is mostly due to difference in technologies that the product is produced. Also, it could be caused by different human exposure pattern. (eg, high population density vs. low population density of the area.

Overall, Since CHBE building was constructed at 2005, so construction drawing are digitized and OnScreen TakeOff software were used for quantity take off to reduce the potential uncertainty in LCI data source. Also, the software used in for assessment, Athena building impact estimator, is designed to fit North America standard and Vancouver region is include in the database. Therefore, other uncertainties such as temporal, spatial and variability between sources are reduced. However, some uncertainty could be introduced due to choices. If the building modeling is over simplified, it might not capture exact cause-effect mechanism.

5.0 List of Indicators Used for Assessment and Expression of Result

It stated in the 2010 report of CHBE whole building life cycle assessment, the mid-point impact assessment methodology developed by the US Environmental Protection Agency was used to filter the LCA results through a set of characterization measures. The impact categories developed by Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) was applied to create environmental impact report. The impact categories and general descriptions are listed as follow[13]:

Global Warming Potential (GWP)

Global warming potential is a measurement of amount of greenhouse gas emission due to production and construction of the building material. The end result for GWP is lead to global warming which create major concerns to current sustainable development. Athena tools provide GWP based on TRACI's characterization factors and the measurement is in kg CO_2 emitted per unit area of the material. GWP is the major impact category that emphasize in this course study.

Acidification Potential (AP)

[13] (Whole building life cycle assessment chemical and biological buildig, 2010)

Acidification potential is created by excessive H+ ions released in to construction soil and surrounding water system. The AP is unavoidable during the construction stage of building life; however, the impact effect could vary due to local existing water and soil condition. The endpoint for AP is acid rain that could lead to serious effect to existing infrastructure and human health. The measurement is AP category is in moles of H+ per unit area.

Human Health Respiratory Potential

TRACI also characterize human health respiratory potential as one of the impact categories to be studied. This category emphasizes the negative affect of population health due to construction. Potential health issue such as breathing problems, asthma, heart disease and other respiratory related issues could be developed due to construction pollution. The impact effect varies greatly based on the region of study, at higher population density area the effect would be amplified. Particulate matter that is less than 2.5 is very hazardous to human health. The unit for measurement is kg PM 2.5 equivalent.

Eutrophication Potential (EP)

Eutrophication potential is created due to enrichment of nutrients that changes the aquatic or terrestrial landscape. Algae growth is a common endpoint to eutrophication potential, and this problem has been affecting many regions. This is also impact category that is regional sensitive due to local condition. The measurement result is in kg nutrients equivalent.

Ozone Depletion Potential

According to Athena impact result, the product and construction stage of CHBE building have very minimal impact on ozone depletion potential. However, ozone depletion could potential create more serious affects on environment and human health such as negative impact on agriculture practice due to UVB light increase, skin cancer, and material damage. The unit for measurement is in kg CFC-11 equivalent.

Smog Potential

According to World Meteorological Organization, Smog potential is related to amount of ozone formed by photochemical reaction from the sun with substance in the air and can affect human and vegetative health by blocking sunlight and creating hazardous concentration of ozone. It has more weighty effect to the region with higher population density. The measurement of smog potential is in unit of kg O_3 equivalent.

6.0 Model Development

Model development for this project was simplified due to development completed in previous studies. Quantity takeoff has already been completed using OnScreen TakeOff and structural and architectural drawings by previous student who worked on this project. For the purpose of current study, structural drawing and OnScreen TakeOff software are used for cross-reference check for consistence of IE input and excel input. OnScreen TakeOff also assists to finding the measurement for different type of functional area of the building. The assumption table completed by previous study was intended to help reader to understand the calculation assumptions for quantity takeoff and logical assumptions were made due to lack of information for assemblies.

CHBE building modeling information for this project is sorted based on Canadian Institute of Quantity Surveyors (CIQS) level 3 elements for input information to Athena impact estimator. The elements is reorganized from previous model as following: foundations, lowest floor construction, upper floor construction, roof construction, walls below grade and walls above grade. Table 5 below provides a summary of level 3 elements and general description of each component.

Table 5 Level 3 Elements and Description

CIVL 498C Level 3 Elements	Description
A11 Foundations	Wall and Column footings
A21 Lowest Floor Construction	Slab on grade
A22 Upper Floor Construction	All columns and beams supporting floors, floors, and stairs structure
A23 Roof Construction	Roof structures and all columns and beams supporting the roof
A31 Walls Below Grade	External walls directly connect to slab on grade
A32 Walls Above Grade	External walls above ground floor which include curtain walls, walls cast in place and concrete block
B11 Partitions	Interior walls, door opening, window opening and envelope

Annex D- impact Estimator Inputs and Assumptions provide a detailed level 3 sorted inputs and assumptions document.

Stage 3 of model improvement emphasizes sorting of the data to fit CIQS level 3 elements requirement as well as possible improvements to the accuracy of previous model. As table 4 summarized in previous section, there were some inconsistency in data entries were found from previous model and adjustment were made correct errors. There are also some uncertainties created due to lack of information. Therefore, site visits to collection the information, and further research and LCA study to expend the LCI database is recommended to improve the accuracy of inventory data.

The concept of reference is to measure the outputs from processes in a given product system required to fulfill the function expressed by the functional unit. [14] Following table summarize the bill of material generated by Athena IE software. This is an estimation of all the types of materials used for building and their corresponding values is produced.

Table 6 CHBE Building Bill of Materials

Material	Quantity	Unit
1/2" Moisture Resistant Gypsum Board	2824.8	m2
1/2" Regular Gypsum Board	14828.5554	m2
6 mil Polyethylene	9490.4888	m2
Aluminum	28.2993	Tonnes
Cold Rolled Sheet	0.439	Tonnes
Commercial(26 ga.) Steel Cladding	3547.0402	m2
Concrete 20 MPa (flyash av)	152.3439	m3
Concrete 30 MPa (flyash av)	7122.8378	m3
Concrete 60 MPa (flyash av)	298.62	m3
Concrete Blocks	79651.3669	Blocks
Concrete Brick	2281.7164	m2
Double Glazed No Coating Air	753.0575	m2
EPDM membrane (black, 60 mil)	907.2421	kg
Expanded Polystyrene	4452.6174	m2 (25mm)
Extruded Polystyrene	1580.9618	m2 (25mm)
FG Batt R11-15	14699.3141	m2 (25mm)
Galvanized Decking	16.3193	Tonnes
Galvanized Sheet	24.9691	Tonnes

[14] (Canada Standard Association, 2006)

Galvanized Studs	18.8024	Tonnes
Glazing Panel	41.3623	Tonnes
Hollow Structural Steel	6.5534	Tonnes
Joint Compound	17.6184	Tonnes
Modified Bitumen membrane	10288.0592	kg
Mortar	1561.6296	m3
Nails	1.8434	Tonnes
Open Web Joists	25.1739	Tonnes
Oriented Strand Board	368.6791	m2 (9mm)
Paper Tape	0.2022	Tonnes
Polyiso Foam Board (unfaced)	11636.8098	m2 (25mm)
Rebar, Rod, Light Sections	647.1304	Tonnes
Residential(30 ga.) Steel Cladding	202.4	m2
Screws Nuts & Bolts	1.4953	Tonnes
Small Dimension Softwood Lumber, Green	1.5667	m3
Small Dimension Softwood Lumber, kiln-dried	0.3683	m3
Softwood Plywood	256.9582	m2 (9mm)
Solvent Based Alkyd Paint	78.6194	L
Water Based Latex Paint	389.7701	L
Welded Wire Mesh / Ladder Wire	4.4244	Tonnes

7.0 Communication of Assessment Result

Figures below provide the summary results of UBC CHBE building life cycle assessment study. Each figure represents a comparison result of potential impact introduced by different CIQS level 3 elements. Color difference of bar represent different stage of the building life cycle, note that only product and construction stage are include in the scope of study for this project, but Athena IE software generate end of life automatically as default setting. The X-axis of each figure lists level 3 elements as following order: foundation, lowest floor construction, upper floor construction, roof constructions, walls below grade, walls above grade and partition. Y-axis shows the potential impact value in its functional unit.

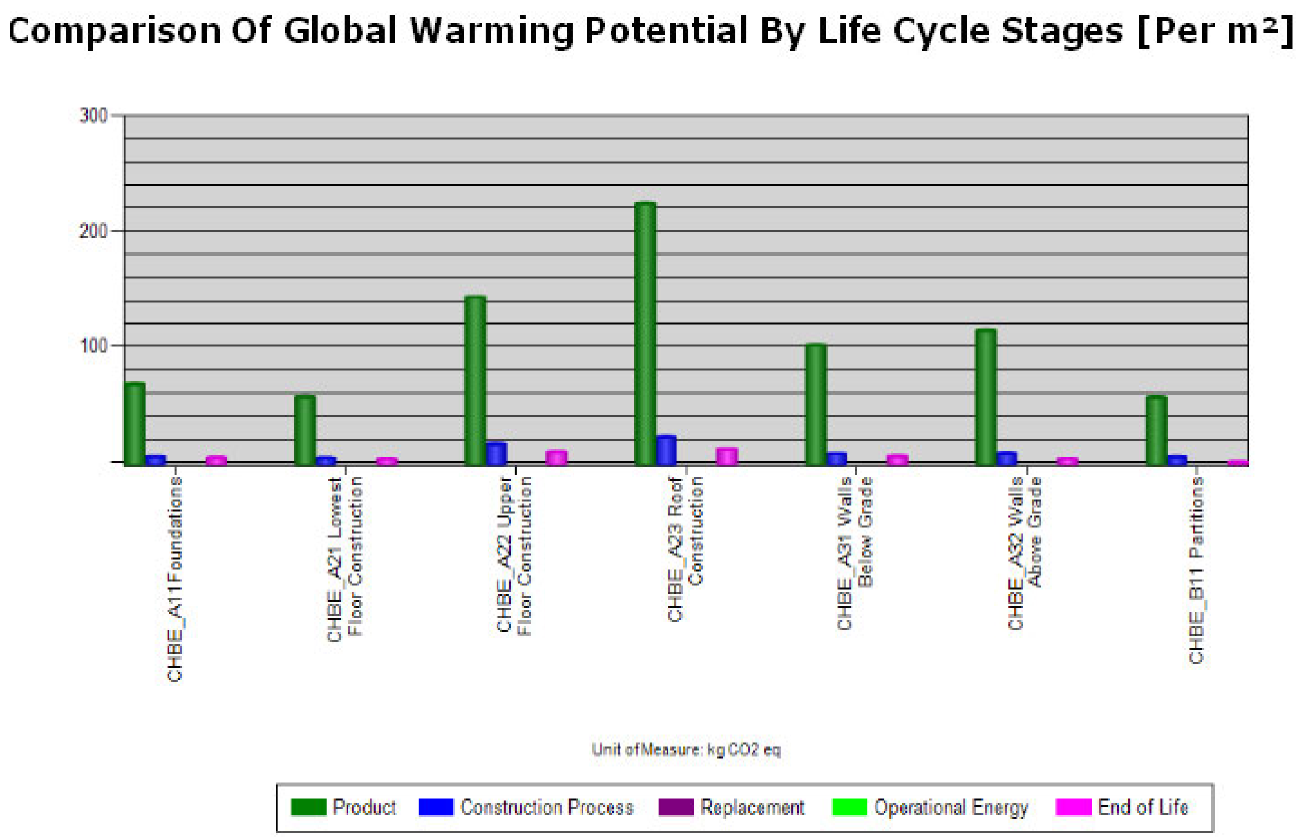

Figure 3 CHBE Building GWP by life cycle stage

Figures 3 summarize global warming potential by life cycle stages. And the functional unit is kg CO_2 per m^2. Figure indicates that production stage has more contribution to GWP, and roof construction has more impact compare with other elements.

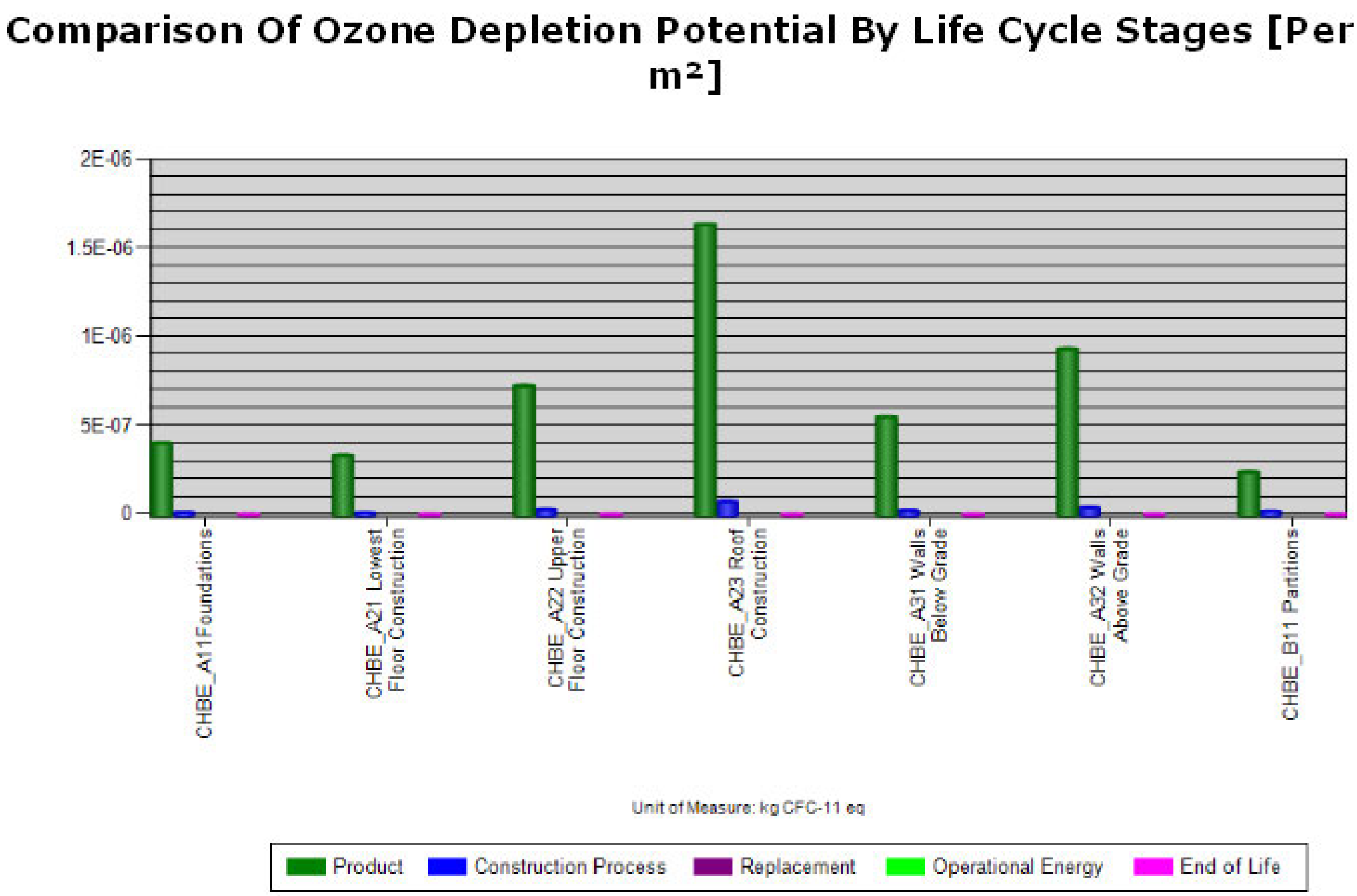

Figure 4 CHBE building Ozone Depletion Potential By Life Cycle Stages

Figures 4 shows ozone depletion potential by life cycle stages of CHBE building. The functional unit is expressed as kg CFC-11per m^2. Figure indicates similar hotspots compare with previous figure; manufacturing and roof construction have more contribution to ozone depletion potential.

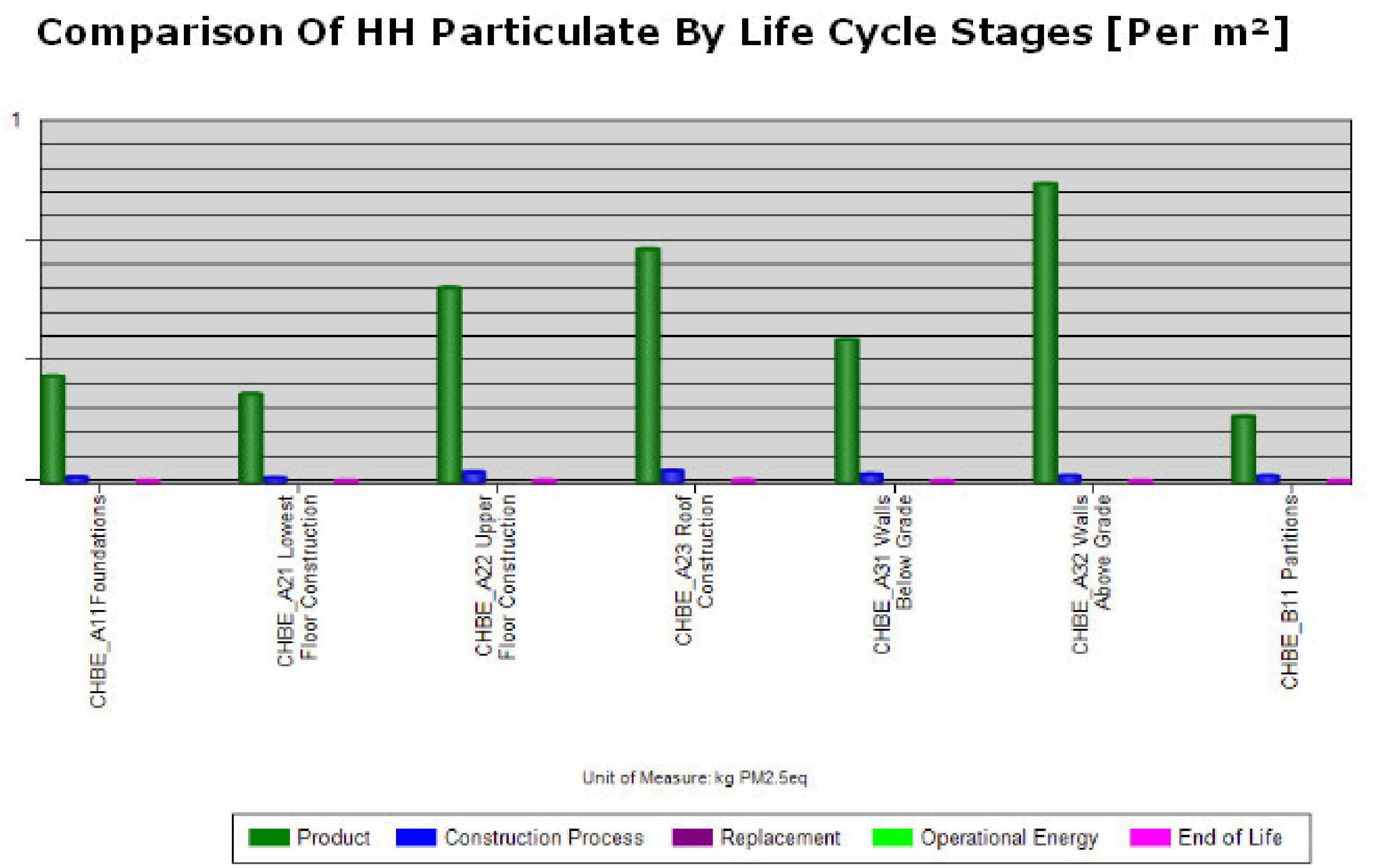

Figure 5 CHBE_ Building HH Particulate by Life Cycle Stage

Human hearth respiratory effect is only impact category that emphasizes human health issue in this study. Figures 5 indicates the potential respiratory risk that could caused by construction of CHBE building due to excess amount of particulate matter 2.5. The functional unit is expressed as kg PM2.5 per m^2. Figure indicates production of material used to walls above grade construction has highest impact on HH particulate.

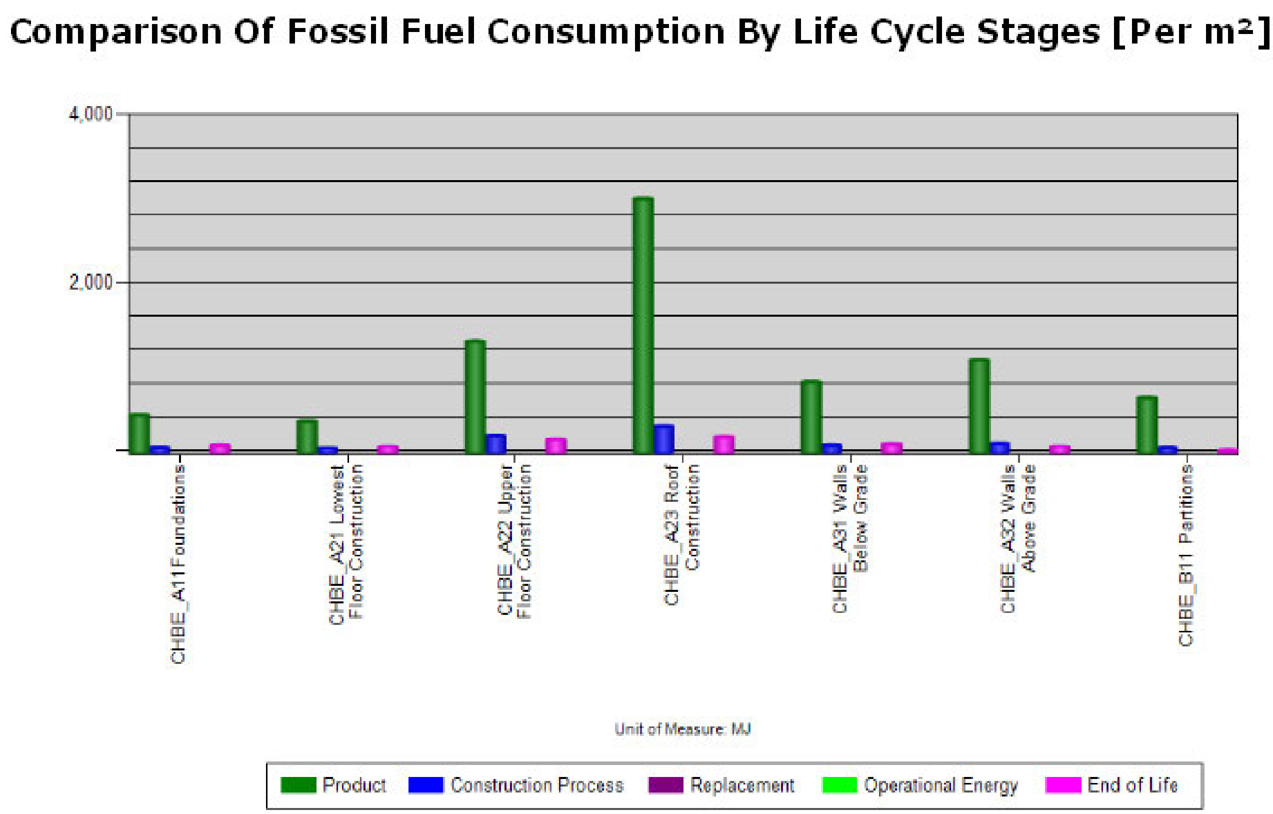

Figure 6 CHBE Building Fossil Fuel Consumption by Life Cycle Stages

According to figure 6, production stage and construction of roof element require most of fossil fuel consumption. Fossil fuel is used in energy generation of each stage. The function unit of consumption is measured in MJ.

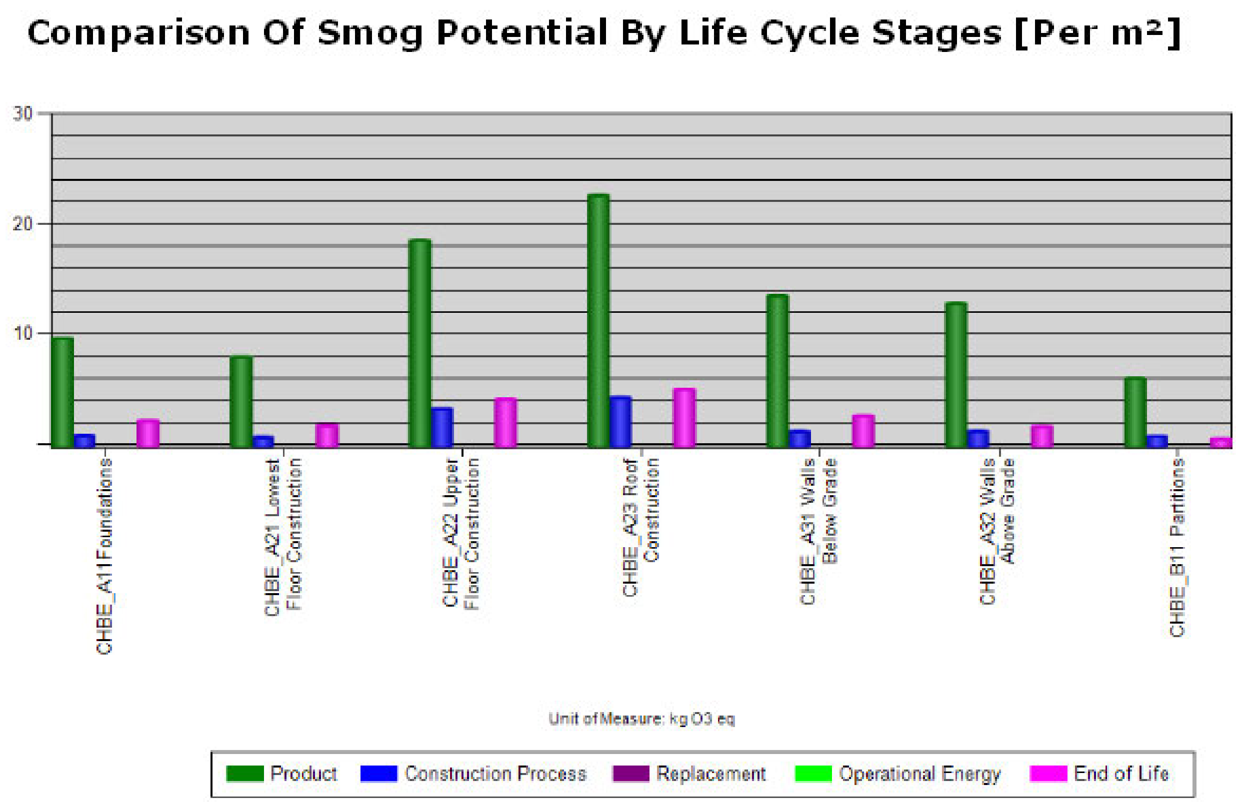

Figure 7 CHBE Building Smog Potential By Life Cycle Stages

Smog potential could cause serious concerns to human and vegetable health by blocking sunlight and creating hazardous concentration of ozone. In CHBE building LCA study, Athena IE software help to indicate the production stage and Roof construction has more impact on smog simulation. The functional unit use in the study was Kg O_3 per $m^{2.}$ The result is summarized in the figure 7 above.

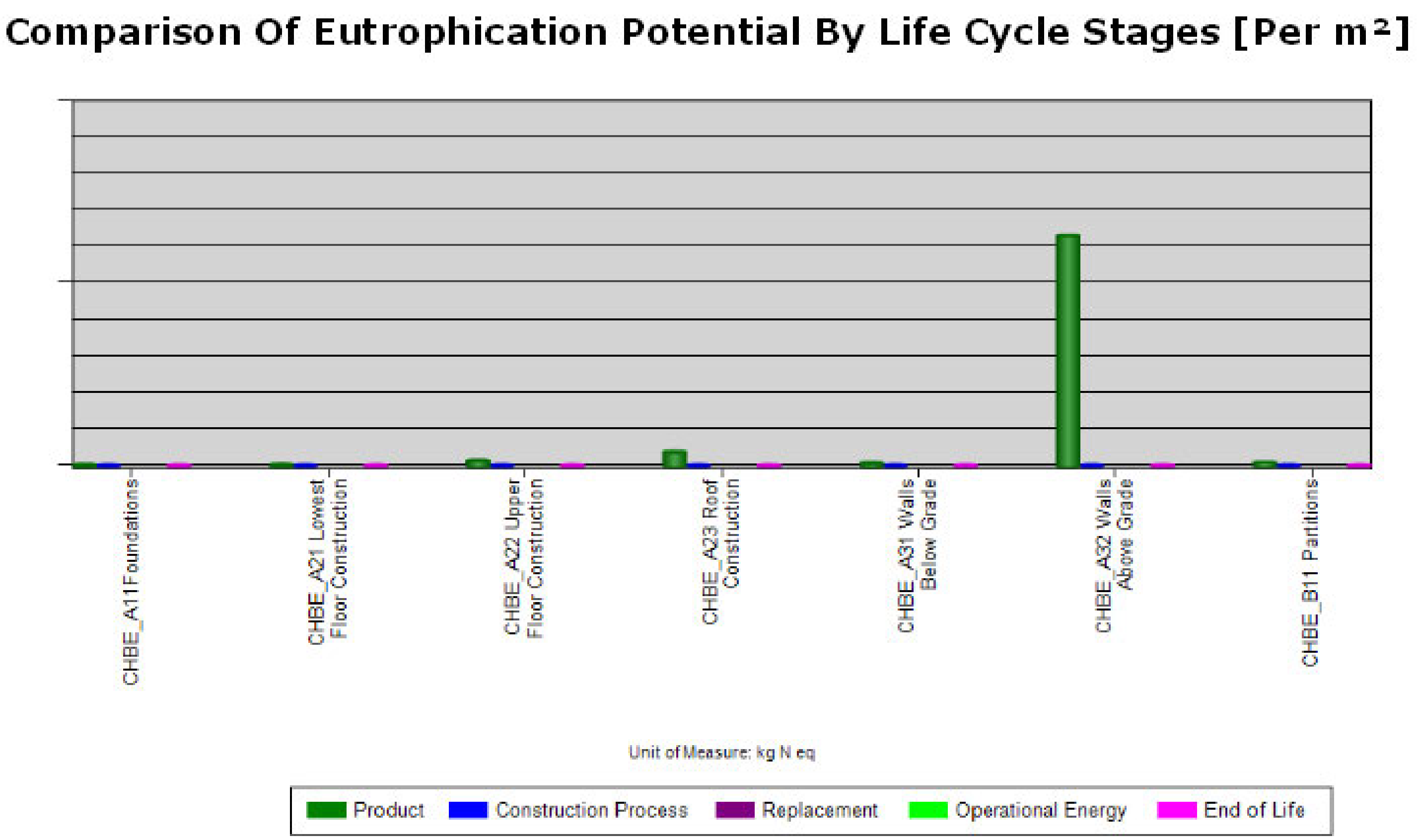

Figure 8 CHBE Building Eutrophication Potential by Life Cycle Stage

Excessive amount of nutrients discharged into water or terrestrial landscape could lead to eutrophication of the area. Based on Athena analysis result, the eutrophication potential due to material production and construction are minimal except the stage for wall above grade construction material production, and figure 8 represent this result.

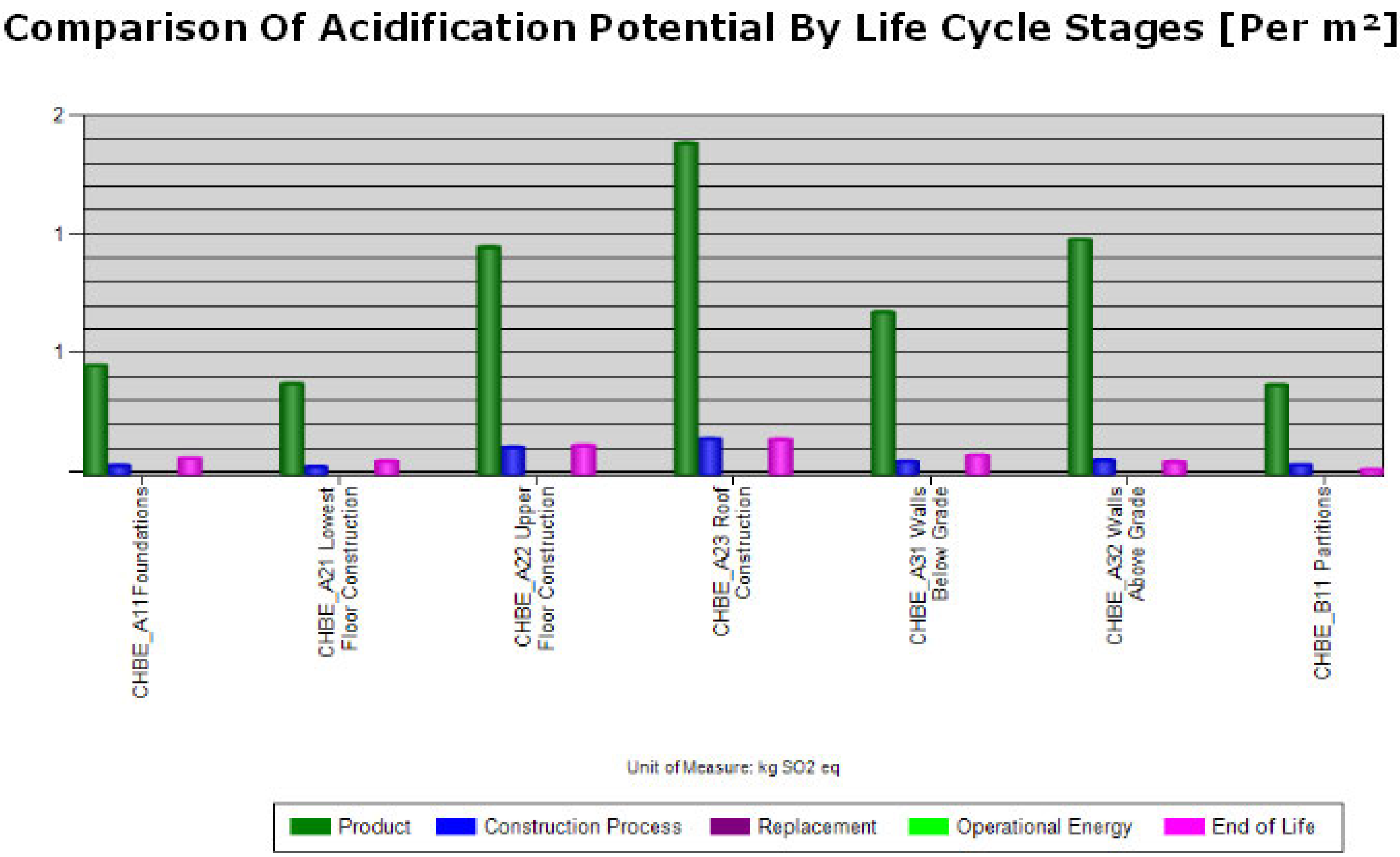

Figure 9 CHBE Building Acidification Potential by Life Cycle Stages

According to TRACI, acidification potential is a measurement of the capacity of the process and material involved from H+ ion. Excessive amount of H+ ions could introduce potential environmental problems to soil and water problem. Figure 9 above indicate the hotspots for acidification potential are production of assemblies and roof construction.

To summarize the above results, production stage generates more environmental concerts to TRACI impact categories. Generally, the construction of roof assemblies of CHBE building has more impact compare with other elements. Therefore, by utilizing mitigation strategies to those two sections would greatly reduce the impact to the environment and human health that we analyzed in this UBC CHBE building life cycle assessment.

The following Annexes will provide a comparative study with other UBC building that completed LCA study using the same goal and scope. Further LCA recommendation is going to be introduced to better operate LCA in building design.

Annex A-Interpretation of Assessment Result

Benchmark Development

Benchmark development is considered as intended aim for this project, and will assist intended audience to make decision with the benchmark result. Benchmark could have the flowing added benefit to LCA study[15]:

1. Development of benchmark allowing intended audience to better interoperate LCA based information.
2. Further suitable application could be formed after benchmark development to utilize the application of LCA study incorporate to design decision-making.

To better apply the benchmark to LCA study, benchmark development shall be made upon same functional unit and same goal and scope for comparative assertion to make the comparison valid. Conclusion cannot be drawn based on different scope and functional unit. The study of UBC building life cycle assessment is based on goal and scope and modeling method. So the result comparison would be valid.

UBC Academic Building Benchmark

The following graph was developed based on October 21, 2013 benchmark result. An average of all the buildings total impact was calculated use as benchmark reference. Figure 10 introduces the comparison to class benchmark for entire building.

[15] (Heiskanen)

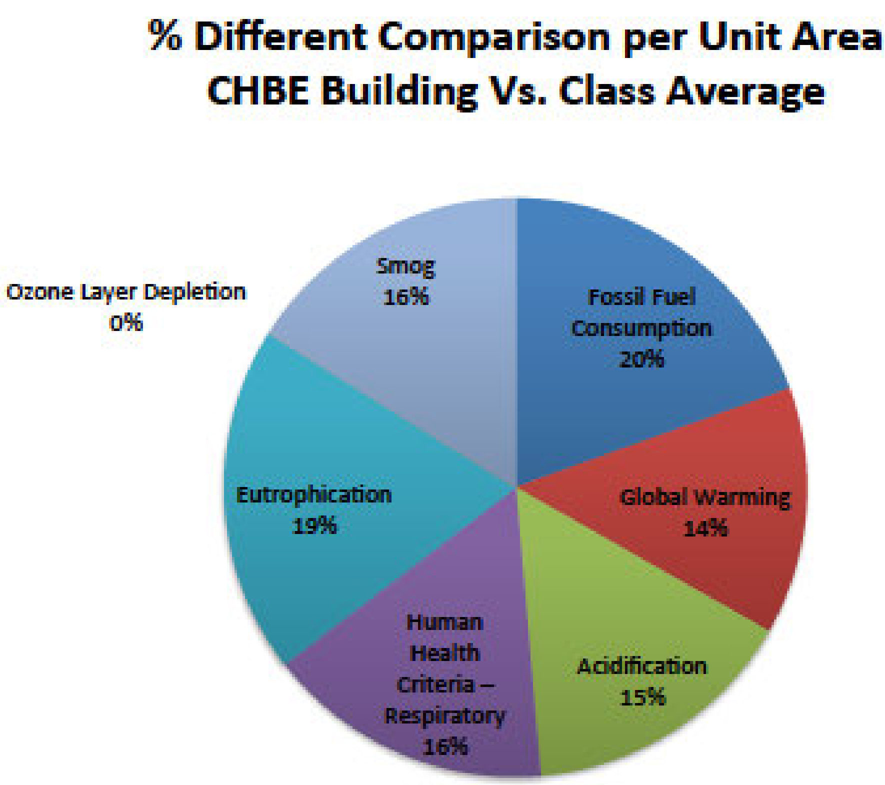

Figure 10 Percentage Comparison CHBE Building VS. Class Average

The differences are within acceptable range since the whole building reduces the potential error could brought up by incorrect sorting for each level 3 elements based on different interoperation among other students. The percentage differences are with the range of 14% to 20%, which is a fair result due to differences functional area, construction time between buildings.

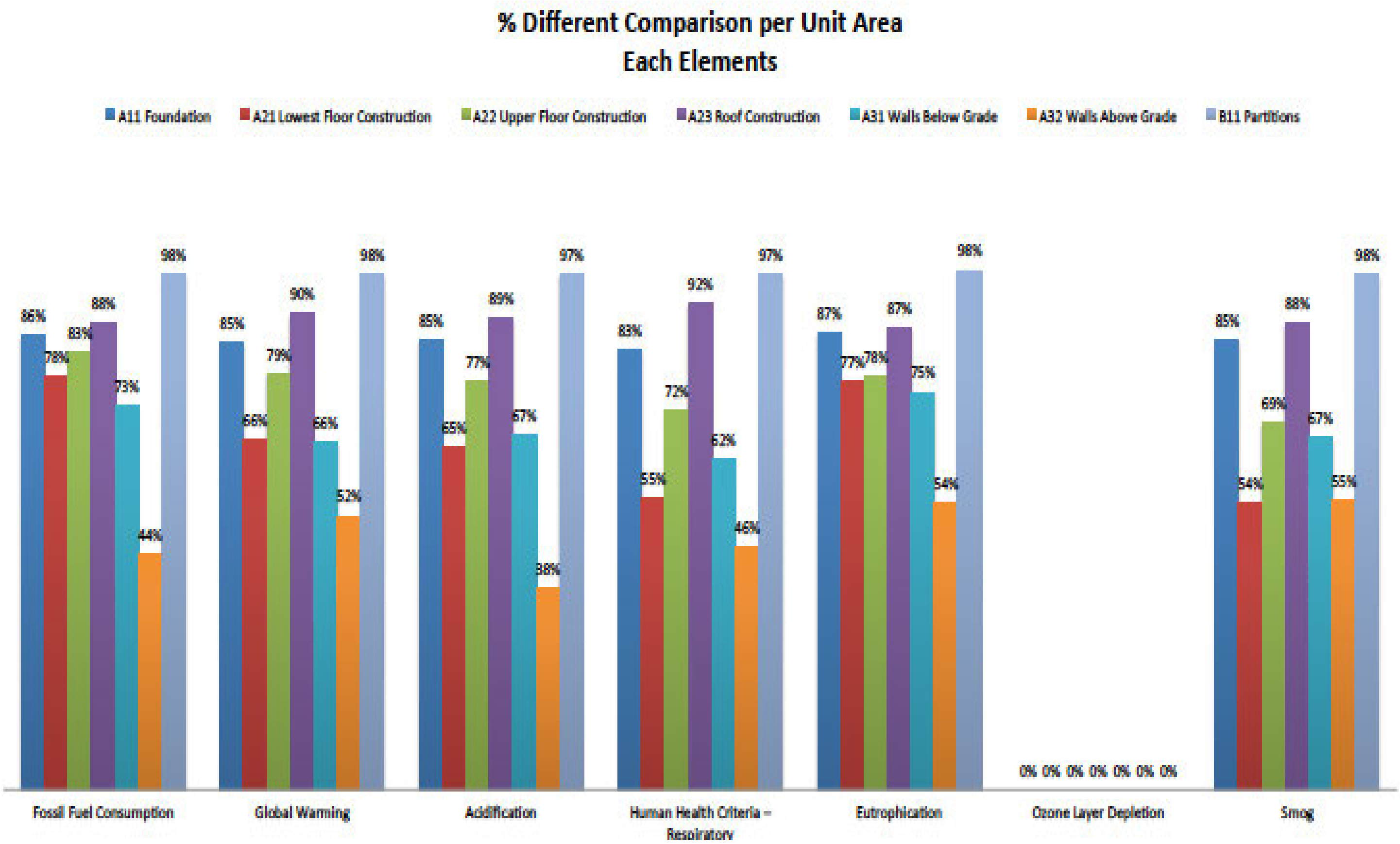

Figure 11 Elements Percentage Difference Comparison CHBE VS. Class Average

Figure 11 above indicates that differences between CHBE buildings to class average are higher when compared with level 3 elements individually. Percentage differences are mostly above 50% and partitions construction has the highest difference compare with class benchmark. The % differences presented above are below class average. However this data graph might not be very representative due to the sorting of the elements could be varies due to individual interpretation and some of modification were made after the completion of the benchmark result. If this results are valid as it show, the difference could occurs due to mostly the type of the construction material. Athena building impact estimator's result indicate most of the effect to impact categories are from production stage and construction stage has relatively low effect to categories.

Annex B –Recommendations for LCA study

Life cycle assessment is a technique developed to evaluate potential environmental impact account for all the product life cycle from manufacturing to end of life disposal. For the purpose of this project, only part of building life was evaluated in the study. Production stage and manufacturing stage are the only two components for evaluation. Usage stage includes use, maintenance, repair, replacement, refurbishment, operational energy use and operational water use are eliminated from the analysis. Also, end of life stage include demolition, transportation, waste processing and disposal were left out of the scope. However, it is essential to include all of the life stages into studies in order to draw valid conclusion for building performance, and make the recommendation to UBC stakeholder. Some of the material in construction stage could potentially have higher cost energy consumption; however, it could save reduce amount of energy required in long run. Therefore, only partial of the stage is not valid to provide conclusive result, further development on modules beyond product and construction is recommended.

After a valid result is found based on LCA study, engineers, LCA practitioners and UBC stakeholders could use the impact to result to utilize the design to minimize the potential negative environmental impact not only in short period time but also take into the consideration of building operation and disposal for its expected service life. At this stage, some of the recommendation could be used based on difference in construction method and material selection to mitigate some of the potential impact.

UBC chemical and biological engineering building was constructed in year 2005. The structural and architectural drawing digitalized and most of the details are legible for the purpose of the quantity takeoff. Previous student did thorough job on tracing of the structural drawing onto OnScreen TakeOff software, very minor mistakes were existed and they are within tolerance range. However, there some lack of data issues when transferring input to Athena IE software due to availability of LCI database. Therefore some assumption must be made such as concrete capacity and flyash percentage.

One of the issues associated with LCA study application is prioritizing impact categories. Some of the mitigation factors to certain impact categories might cause more serious problem to other one. For example, in CHBE building study result, choose the material that has lot eutrophication potential might increase other environmental impact such as GWP, and acidification potential. Since some of the problems are regional sensitive and problems scales are also different, it is important to prioritizing when making design decision.

A continuing development involve life cycle module beyond the production and construction is recommend to better assist decision-making. To improve data quality, all of the building drawing should be unified, digitalized, and imported to Onscreen TakeOff software for consistence, and this will also reduce temporal uncertainty. Periodical checking and updating of the database is also suggestion to improve the accuracy and availability of the data source. With the more valid result that include entire building cycle analysis, UBC could reference the result when doing further construction, and find the most utilized material selection, construction method, structural design component, and demolition and disposal method to minimize the potential impacts.

Annex C- Author Reflection

This is the first LCA course I have taken so far in my academic history; however, I have taken some sustainable development related course such as Civil 200 engineering and sustainable development. The following information was delivered throughout the term: an overview and history of LCA development; organization and standard of LCA; development of whole building LCA study and uncertainty in LCA study.

At the beginning of the course, the idea of sustainable development is the driven force to me to get registered in this course. As the term flow, I realize LCA is a PRACTICAL tool that could really help to make more sustainable decision to real life project rather than the vague theme of going green. LCA provide a scientific back up for decision making. The most interesting part of LCA is it helps to develop the analytical and research skill. In order to complete this final project, I have to go through a lot of online articles and going back and forth between drawings and data. It was a tedious process, but rewards are promising. I might not be the greatest student in this class due to amount of course load I am having right now, but I definitely enjoyed this course. I think this course really combine sustainable theory and engineer technique together, which I enjoyed the most.

Table 7 Graduate Study Attributes

	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	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.	IA = introduced & applied	LCA knowledge was introduced and applied to the final project
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	DA = developed & applied	The analytical skill was further developed and applied in to completion of final project
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.	DA = developed & applied	Some of the final report component required research to obtain information
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.	A = applied	This skill was applied to complete outline steps to operationalize LCA method

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	Athena IE software and Onscreen TakeOff were introduced and applied for the final program, the skill was developed
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	DA = developed & applied	Team work mostly completed during class discussion, and completion of benchmark
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	Written communication skill was applied to complete final report
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	
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	A = applied	LCA study is analyzing the environmental impact of the product life cycle and associated with society aspect

		aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.		
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	A = applied	
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	Building Cost estimate
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.	IDA = introduced, developed & applied	

Annex D-Impact Estimator Inputs and Assumption

Table 8 IE Input Documents

Elements	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/Measured	IE Inputs
A11 Foundations	3192.25	m2	Concrete Footing				
				1.2.1 Footing_F1			
					Length (m)	9	9
					Width (m)	1.8	1.8
					Thickness (mm)	450	450
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.2 Footing_F2			
					Length (m)	112.32	112.32
					Width (m)	5.2	5.2
					Thickness (mm)	500	500
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.3. Footing_F3			
					Length (m)	10	10
					Width (m)	3	3
					Thickness (mm)	450	450
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.4 Footing_F4			
					Length (m)	9.25	9.25
					Width (m)	2.3	2.3
					Thickness (mm)	350	350
					Concrete (MPa)	30	30

					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.5 Footing_F5			
					Length (m)	5.25	5.25
					Width (m)	1.75	1.75
					Thickness (mm)	300	300
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.6 Footing_F6			
					Length (m)	17.6	17.6
					Width (m)	3.2	3.2
					Thickness (mm)	500	500
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.7 Footing_F7			
					Length (m)	1.6	1.6
					Width (m)	2.7	2.7
					Thickness (mm)	300	300
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.2.8 Footing_F8			
					Length (m)	2.5	2.5
					Width (m)	2.75	2.75
					Thickness (mm)	450	450
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.2.9 Footing_F9			
					Length (m)	23	23
					Width (m)	2.3	2.3
					Thickness (mm)	400	400

					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.2.10 Footing_F10			
					Length (m)	10.2	10.2
					Width (m)	1.7	1.7
					Thickness (mm)	300	300
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.11 Footing_SF1			
					Length (m)	12	12
					Width (m)	0.45	0.45
					Thickness (mm)	250	250
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.2.12 Footing_SF3			
					Length (m)	43.2	43.2
					Width (m)	1.2	1.2
					Thickness (mm)	500	500
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.13 Footing_SF4			
					Length (m)	30	30
					Width (m)	1.5	1.5
					Thickness (mm)	450	450
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M

				1.2.14 Footing_SF5			
					Length (m)	69.6	43.2
					Width (m)	2.4	1.2
					Thickness (mm)	500	500
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.2.15 Footing_SF6			
					Length (m)	45	45
					Width (m)	4.5	4.5
					Thickness (mm)	250	250
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	10M	10M
				1.2.16 Footing_SF7			
					Length (m)	79	79
					Width (m)	7.5	7.5
					Thickness (mm)	300	300
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.2.17 Footing_SF8			
					Length (m)	14	14
					Width (m)	4.5	4.5
					Thickness (mm)	250	250
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.2.18 Footing_450mm_Main Section_NorthWall			
					Length (m)	13.80	13.80
					Width (m)	2.30	2.30
					Thickness	400.00	400.00

					(mm)		
					Concrete (MPa)	30	30
					Concrete flyash %	-	average
					Rebar	15M	15M
A21 Lowest Floor Construction	3192.25	m^2	Concrete slab on grade	1.1.5 SOG_450mm_Basement			
					Length (m)	56.50	56.50
					Width (m)	56.50	56.50
					Thickness (mm)	450	200
					Concrete (MPa)	32	30
					Concrete flyash %	-	average
A22 Upper floor construction	7596.56	m^2	Concrete slab on grade	1.1.1 SOG_150mm_GroundLevel_Middle Section1			
					Length (m)	3.57	3.57
					Width (m)	3.57	3.57
					Thickness (mm)	150	200
					Concrete (MPa)	32	30
					Concrete flyash %	-	average
				1.1.2 SOG_150mm_GroundLevel_Middle Section2			
					Length (m)	9.41	9.41
					Width (m)	9.41	9.41
					Thickness (mm)	150	200
					Concrete (MPa)	32	30
					Concrete flyash %	-	average
				1.1.3 SOG_200mm_GroundLevel_East Section			
					Length (m)	27.51	27.51
					Width (m)	27.51	27.51
					Thickness (mm)	200	200
					Concrete	32	30

					(MPa)		
					Concrete flyash %	-	average
				1.1.4 SOG_200mm_GroundLevel_West Section			
					Length (m)	29.58	29.58
					Width (m)	29.58	29.58
					Thickness (mm)	200	200
					Concrete (MPa)	32	30
					Concrete flyash %	-	average
			Stairs	1.2.19 Stairs Main East Stairwell			
					Length (m)	98	98
					Width (m)	1.277	1.277
					Thickness (mm)	237	237
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Rebar	-	15M
				1.2.19 Stairs_Main West Stairwell			
					Length (m)	97	97
					Width (m)	1.277	1.277
					Thickness (mm)	237	237
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Rebar	-	15M
			Concrete Beams and Columns	3.1.1 Column_Concrete_Beam_Concrete_GroundLevel_Main Section Lecture			
					Number of Beams	3	3
					Number of Columns	7	7
					Floor to floor height (m)	8	8
					Bay sizes (m)	12.2	12.2
					Supported span (m)	5.62	5.62
					Live load (kPa)	-	4.8

				3.1.2 Column_Concrete_Beam_N/A_GroundLEvel-Level3_MainSection			
					Number of Beams	0	0
					Number of Columns	18	18
					Floor to floor height (m)	8	8
					Bay sizes (m)	3.96	3.96
					Supported span (m)	3.96	3.96
					Live load (kPa)	-	4.8
				3.1.3 Column_Concrete_Beam_N/A_Level2_Main Section			
					Number of Beams	0	0
					Number of Columns	18	18
					Floor to floor height (m)	4	4
					Bay sizes (m)	7.29	7.29
					Supported span (m)	7.29	7.29
					Live load (kPa)	-	4.8
				3.1.4 Column_Concrete_Beam_N/A_Level3_Main Section			
					Number of Beams	0	0
					Number of Columns	23	23
					Floor to floor height (m)	4	4
					Bay sizes (m)	6.7	6.7
					Supported span (m)	6.7	6.7
					Live load (kPa)	-	4.8
				3.1.5 Column_Concrete_Beam_N/A_Level4_Main Section			
					Number of Beams	0	0
					Number of Columns	34	34
					Floor to floor	4	4

					height (m)		
					Bay sizes (m)	5.53	5.53
					Supported span (m)	5.53	5.53
					Live load (kPa)	-	4.8
				3.1.6 Column_Concrete_Beam_N/A_Level5_Main Section			
					Number of Beams	0	0
					Number of Columns	34	34
					Floor to floor height (m)	4	4
					Bay sizes (m)	5.51	5.51
					Supported span (m)	5.51	5.51
					Live load (kPa)	-	4.8
			Steel conlumns	3.2.1 Column_Steel_Beam_N/A_GroundLevel East Section			
					Number of Beams	0	0
					Number of Columns	5	5
					Floor to floor height (m)	4	4
					Bay sizes (m)	12.2	12.2
					Supported span (m)	12.2	12.2
					Live load (kPa)	-	4.8
				3.2.2 Column_Steel_Beam_N/A_GroundLevel Main Section			
					Number of Beams	0	0
					Number of Columns	10	10
					Floor to floor height (m)	4	4
					Bay sizes (m)	7.71	7.71
					Supported span (m)	7.71	7.71
					Live load (kPa)	-	4.8

				3.2.3 Column_Steel_Beam_N/A_GroundLevel West Section			
					Number of Beams	0	0
					Number of Columns	12	12
					Floor to floor height (m)	4	4
					Bay sizes (m)	8.53	8.53
					Supported span (m)	8.53	8.53
					Live load (kPa)	-	4.8
				3.2.4 Column_Steel_Beam_N/A_Level2 East Section			
					Number of Beams	0	0
					Number of Columns	5	5
					Floor to floor height (m)	4	4
					Bay sizes (m)	12.2	12.2
					Supported span (m)	12.2	12.2
					Live load (kPa)	-	4.8
				3.2.5 Column_Steel_Beam_N/A_Level2 West Section			
					Number of Beams	0	0
					Number of Columns	10	10
					Floor to floor height (m)	4	4
					Bay sizes (m)	7.67	7.67
					Supported span (m)	7.67	7.67
					Live load (kPa)	-	4.8
			Concrete Suspended Slab	4.1.1 Floor_ConcreteSuspendedSlab_200mm			
					Floor Width (m)	1271.28	1271.28
					Span (m)	30	30
					Concrete	3500	4000

					(MPa)		
					Concrete flyash %	-	average
					Life load (kPa)	-	75
A23 Roof Construction	1,164.15	m2	Concrete Columns	3.1.7 Column_Concrete_Beam_N/A_Level6_Main Section			
					Number of Beams	0	0
					Number of Columns	34	34
					Floor to floor height (m)	4	4
					Bay sizes (m)	5.51	5.51
					Supported span (m)	5.51	5.51
					Live load (kPa)	-	4.8
			Concrete Suspended Slab				
				5.1.1 Roof_ConcreteSuspendedSlab_Main Section 200mm			
					Floor Width (m)	119.4	119.4
					Span (m)	9.75	9.75
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Life load (kPa)	-	2.4
				Envelope	Category	Roof Envelopes	Roof Envelopes Standard Modified Bitumen Membrane 2 ply
					Material	-	
					Thickness	-	-
					Category	Insulation	Insulation
					Material	-	Polyisocyanurate Foam
					Thickness	-	100.00
					Category	Vapour Barrier	Vapour Barrier
					Material	-	Polyethylene 6

					Thickness	-	mil -
			Open Web Steel Joist				
				5.2.1 Roof_OWSJ_East Section			
					Roof Width (m)	35.8	3554.22
					Roof Length (m)	21.70	17.35
					With or W/out Concrete Topping	Topping Included	Topping Included
					Live load (kPa)	-	2.4
				Envelope	Category	Roof Envelopes	Roof Envelopes
					Material	-	Standard Modified Bitumen Membrane 2 ply
					Thickness	-	-
					Category	Insulation	Insulation
					Material	-	Polyisocyanurate Foam
					Thickness	-	100.00
					Category	Vapour Barrier	Vapour Barrier
					Material	-	Polyethylene 6 mil
					Thickness	-	-
				5.2.2 Roof_OWSJ_West Section			
					Roof Width (m)	35.88	35.88
					Roof Length (m)	24.30	24.30
					With or W/out Concrete Topping	Topping Included	Topping Included
					Live load (kPa)	-	2.4
				Envelope	Category	Roof Envelopes	Roof Envelopes
					Material	-	Standard Modified Bitumen

							Membrane 2 ply
					Thickness	-	-
					Category	Insulation	Insulation
					Material	-	Polyisocyanurate Foam
					Thickness	-	100.00
					Category	Vapour Barrier	Vapour Barrier
					Material	-	Polyethylene 6 mil
					Thickness	-	-
A31 Walls Below Grade	832.04	m2	Cast-in-Place	2.1.4 Wall_Cast-in-Place W4A			
					Length (m)	137	137
					Height (m)	4	4
					Thickness (mm)	300	300
					Concrete (MPa)	-	60
					Concrete flyash %	-	average
					Rebar	-	20M
				Envelope	Category	Vapour Barrier	Vapour Barrier
					Material	-	Polyethylene 6 mil
					Thickness	-	-
				2.1.5 Wall_Cast-in-Place_W4B			
					Length (m)	100	100
					Height (m)	4	4
					Thickness (mm)	300	300
					Concrete (MPa)	-	60
					Concrete flyash %	-	average
					Rebar	-	20M
				Envelope	Category	Vapour Barrier	Vapour Barrier
					Material	Air/vapour Barrier	Polyethylene 6 mil
					Thickness	-	-
			Concrete Block	2.2.6 Wall_ConcreteBlock W9			
					Length (m)	20	20
					Height (m)	4	4
					Rebar	-	15M
				Envelope	Category	Vapour Barrier	Vapour Barrier

					Material	Air/vapour Barrier	Polyethylene 6 mil
					Thickness	-	-
A31 Walls above Grade	3311.1	m2		2.1.2 Wall_Cast-in-Place_W1C			
					Length (m)	527	527
					Height (m)	4	4
					Thickness (mm)	300	300
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Rebar	-	20M
				Window Opening	Number of Windows	140	128
					Total Window Area (m2)	560	2151.68
					Frame Type	Fixed, Aluminum Frame	Fixed, Aluminum Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Insulation	Insulation
					Material	Spray foam insulation	Polystyrene Expanded
					Thickness	50	50
					Category	Cladding	Insulation
					Material	Brick	Brick - Concrete
					Thickness	92	-
					Category	Vapour Barrier	Vapour Barrier
					Material	Air/vapour Barrier	Polyethylene 6 mil
					Thickness	-	-
				2.1.3 Wall_Cast-in-Place_W3			
					Length (m)	347	347
					Height (m)	4	4
					Thickness (mm)	300	300
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Rebar	-	20M
				Door Opening	Number of Doors	4	4

	Door Type	-	Steel Exterior Door, 50% Glazing
Envelope	Category	Cladding	Cladding
	Material	Galvalume Corrugated Cladding	Steel Cladding - Commercial (26 ga.)
	Thickness	-	-
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness	25	25
	Category	Vapour Barrier	Vapour Barrier
	Material	Air/vapour Barrier	Polyethylene 6 mil
	Thickness	-	-
2.1.6 Wall_Cast-in-Place_W6			
	Length (m)	66	66
	Height (m)	4	4
	Thickness (mm)	300	300
	Concrete (MPa)	30	30
	Concrete flyash %	-	average
	Rebar	-	20M
Door Opening	Number of Doors	4	4
	Door Type	-	Steel Exterior Door, 50% Glazing
Envelope	Category	Insulation	Insulation
	Material	Spray foam insulation	Polystyrene Expanded
	Thickness	50	50
	Category	Cladding	Insulation
	Material	Brick	Brick - Concrete
	Thickness	92	-
	Category	Gypsum Board	Gypsum Board
	Material	Gypsum Board	Gypsum Regular
	Thickness	16	1/2"
	Category	Vapour Barrier	Vapour Barrier
	Material	Air/vapour Barrier	Polyethylene 6 mil
	Thickness	-	-
2.2.4 Wall_ConcreteBlock_W1D			

					Length (m)	46	46
					Height (m)	4	4
					Rebar	-	15M
				Envelope	Category	Insulation	Insulation
					Material	Spray foam insulation	Polystyrene Expanded
					Thickness	50	50
					Category	Cladding	Insulation
					Material	Brick	Brick - Concrete
					Thickness	92	-
					Category	Gypsum Board	Gypsum Board
					Material	Gypsum Board	Gypsum Regular
					Thickness	16	1/2"
					Category	Vapour Barrier	Vapour Barrier
					Material	Air/vapour Barrier	Polyethylene 6 mil
					Thickness	-	-
				2.2.5 Wall_ConcreteBlock_W8			
					Length (m)	81	81
					Height (m)	4	4
					Rebar	-	10M
			Curtain Wall				
				2.3.1 Wall_CurtainWall_GlassShelter_Main Section__NorthWall			
					Length (m)	41	41
					Height (m)	3	3
					Percent Viewable Glazing	100	100
					Percent Spandrel Panel	0	0
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
				2.3.2 Wall_CurtainWall_GlassShelter_Main Section__Part1			
					Length (m)	6	6
					Height (m)	2	2

					Percent Viewable Glazing	100	100
					Percent Spandrel Panel	0	0
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
				2.3.3 Wall_CurtainWall_GlassShelter_ Main Section Part2			
					Length (m)	15	15
					Height (m)	2.75	2.75
					Percent Viewable Glazing	100	100
					Percent Spandrel Panel	0	0
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
				2.3.4 Wall CurtainWall W16 Windows			
					Length (m)	8	8
					Height (m)	4	4
					Percent Viewable Glazing	100	100
					Percent Spandrel Panel	0	0
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
				2.3.5 Wall CurtainWall W18 Windows			
					Length (m)	10	10

					Height (m)	4	4
					Percent Viewable Glazing	100	100
					Percent Spandrel Panel	0	0
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
				2.3.6 Wall_CurtainWall_W6_Windows			
					Length (m)	113	113
					Height (m)	4	4
					Percent Viewable Glazing	100	100
					Percent Spandrel Panel	0	0
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
				2.3.7 Wall_CurtainWall_W9&W11&W12_Windows			
					Length (m)	167	167
					Height (m)	4	4
					Percent Viewable Glazing	60	60
					Percent Spandrel Panel	40	40
					Thickness of Insulation (mm)	0	0
					Spandrel Type (Metal/Glass)	Metal	Metal
			Concrete Tilt Up				

2.6.1 Wall_ConcreteTilt -Up_W2A			
	Length (m)	215	215
	Height (m)	4	4
	Thickness (mm)	190	200
	Concrete (MPa)	-	30
	Concrete flyash %	-	average
	Rebar	-	10M
Window Opening	Number of Windows	41	41
	Total Window Area (m2)	203	203
	Frame Type	Fixed, Aluminum Frame	Fixed, Aluminum Frame
	Glazing Type	-	Standard Glazing
Door Opening	Number of Doors	3	3
	Door Type	-	Aluminum Exterior Door, 80% glazing
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Vapour Barrier	Vapour Barrier
	Material	Air/vapour Barrier	Polyethylene 6 mil
	Category	Insulation	Insulation
	Material	Acoustic Batt	Fiberglass Batt
	Thickness	89	89
	Category	-	Cladding
	Material	-	Steel Cladding - Commercial (26 ga.)
	Thickness	-	-
2.6.2 Wall_ConcreteTilt -Up_W2B			
	Length (m)	119	119
	Height (m)	4	4
	Thickness (mm)	200	200
	Concrete	-	30

					(MPa)		
					Concrete flyash %	-	average
					Rebar	-	10M
				Door Opening	Number of Doors	12	12
					Door Type	-	Aluminum Exterior Door, 80% glazing
				Envelope	Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Vapour Barrier	Vapour Barrier
					Material	Air/vapour Barrier	Polyethylene 6 mil
					Category	Insulation	Insulation
					Material	Acoustic Batt	Fiberglass Batt
					Thickness	89	89
					Category	-	Cladding
					Material	-	Steel Cladding - Commercial (26 ga.)
					Thickness	-	-
				2.6.3 Wall_ConcreteTilt-Up_W2C			
					Length (m)	120	120
					Height (m)	4	4
					Thickness (mm)	300	200
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Rebar	-	15M
				Window Opening	Number of Windows	8	8
					Total Window Area (m2)	32	32
					Frame Type	Fixed, Aluminum Frame	Fixed, Aluminum Frame
					Glazing Type	-	Standard Glazing
				Door Opening	Number of Doors	2	2
					Door Type	-	Aluminum Exterior Door,

							80% glazing
				Envelope	Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Vapour Barrier	Vapour Barrier
					Material	Air/vapour Barrier	Polyethylene 6 mil
					Category	Insulation	Insulation
					Material	Acoustic Batt	Fiberglass Batt
					Thickness	89	89
					Category	-	Cladding
					Material	-	Steel Cladding - Commercial (26 ga.)
					Thickness	-	-
B11 Partitions	1044.16	m2	Steel Stud				
				2.4.1 Wall_SteelStud_P1A-E			
					Length (m)	447	447
					Height (m)	4	4
					Sheathing Type	None	None
					Stud Spacing	400oc	400oc
					Stud Weight	-	Light (25Ga)
					Stud Thickness	39 x 92	39 x 92
				Envelope	Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
				2.4.2 Wall_SteelStud_P2A			
					Length (m)	224	224
					Height (m)	4	4
					Sheathing Type	None	None
					Stud Spacing	400oc	400oc
					Stud Weight	-	Light (25Ga)
					Stud	39 x 92	39 x 92

					Thickness		
				Door Opening	Number of Doors	30	30
					Door Type	-	Hollow Core Wood Interior Door
				Envelope	Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Insulation	Insulation
					Material	Acoustic Batt	Fiberglass Batt
					Thickness	89	89
				2.4.3 Wall_SteelStud_P2&C			
					Length (m)	294	294
					Height (m)	4	4
					Sheathing Type	None	None
					Stud Spacing	400oc	400oc
					Stud Weight	-	Light (25Ga)
					Stud Thickness	39 x 92	39 x 92
				Envelope	Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Insulation	Insulation
					Material	Acoustic Batt	Fiberglass Batt
					Thickness	89	89
				2.4.4			

Wall_SteelStud_P 2B			
	Length (m)	3	3
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	400oc	400oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 152	39 x 152
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Insulation	Insulation
	Material	Acoustic Batt	Fiberglass Batt
	Thickness	89	89
2.4.5 Wall_SteelStud_P 3			
	Length (m)	65	65
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	600oc	600oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 92	39 x 92
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"

					Thickness	-	-
					Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Insulation	Insulation
					Material	Acoustic Batt	Fiberglass Batt
					Thickness	89	89
				2.4.6 Wall_SteelStud_P4			
					Length (m)	12	12
					Height (m)	4	4
					Sheathing Type	None	None
					Stud Spacing	400oc	400oc
					Stud Weight	-	Light (25Ga)
					Stud Thickness	39 x 152	39 x 152
				Envelope	Category	-	Gypsum Board
					Material	Tile Backer Board	Gypsum Moisture Resistant 1/2"
					Thickness	-	-
					Category	-	Gypsum Board
					Material	Tile Backer Board	Gypsum Moisture Resistant 1/2"
					Thickness	-	-
				2.4.7 Wall_SteelStud_P9			
					Length (m)	55	55
					Height (m)	4	4
					Sheathing Type	None	None
					Stud Spacing	400oc	400oc
					Stud Weight	-	Light (25Ga)
					Stud Thickness	39 x 92	39 x 92
				Envelope	Category	Gypsum Board	Gypsum Board
					Material	-	Gypsum Regular 1/2"
					Thickness	-	-
					Category	Insulation	Insulation
					Material	Acoustic Batt	Fiberglass Batt
					Thickness	89	89

2.4.8 Wall_SteelStud_F 1A&B			
	Length (m)	527	527
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	600oc	600oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 92	39 x 92
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Moisture Resistant 1/2"
	Thickness	-	-
2.4.9 Wall_SteelStud_F 2			
	Length (m)	91	91
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	600oc	600oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 92	39 x 92
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
2.4.10 Wall_SteelStud_F 8			
	Length (m)	33	33
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	400oc	400oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 92	39 x 92
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-

2.4.11 Wall_SteelStud_ W1A			
	Length (m)	10	10
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	400oc	400oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 92	39 x 92
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Vapour Barrier	Vapour Barrier
	Material	Air/vapour Barrier	Polyethylene 6 mil
	Category	Cladding	Insulation
	Material	Brick	Brick - Concrete
	Thickness	92	-
	Category	Insulation	Insulation
	Material	Spray foam insulation	Polystyrene Expanded
	Thickness	50	50
2.4.12 Wall_SteelStud_ W1B			
	Length (m)	36	36
	Height (m)	4	4
	Sheathing Type	None	None
	Stud Spacing	400oc	400oc
	Stud Weight	-	Light (25Ga)
	Stud Thickness	39 x 152	39 x 152
Envelope	Category	Gypsum Board	Gypsum Board
	Material	-	Gypsum Regular 1/2"
	Thickness	-	-
	Category	Vapour Barrier	Vapour Barrier
	Material	Air/vapour Barrier	Polyethylene 6 mil
	Category	Cladding	Insulation
	Material	Brick	Brick - Concrete

					Thickness	92	-
					Category	Insulation	Insulation
					Material	Spray foam insulation	Polystyrene Expanded
					Thickness	50	50
			Wood Stud				
				2.5.1 Wall_WoodStud_ F6			
				Envelope	Length (m)	33	33
					Height (m)	4	4
					Wall Type	Interior	Interior
					Sheathing Type	-	OSB
					Stud Spacing	-	600oc
					Stud Type	-	Green Lumber
					Stud Thickness	-	38 x 64
					Category	Insulation	Insulation
					Material	Acoustic Insulation	Polystyrene Extruded
					Thickness	25	25
					Category	Paint	Paint
					Material	-	Alkyd Solvent Based
					Thickness	-	-
				2.5.2 Wall_WoodStud_ F7			
				Envelope	Length (m)	33	33
					Height (m)	4	4
					Wall Type	Interior	Interior
					Sheathing Type	-	OSB
					Stud Spacing	-	600oc
					Stud Type	-	Green Lumber
					Stud Thickness	-	38 x 64
					Category	Paint	Paint
					Material	-	Alkyd Solvent Based
					Thickness	-	-
			2.1 Cast In Place				
				2.1.1 Wall_Cast-in-Place P7			
					Length (m)	363	363

					Width (m)	4	4
					Thickness (mm)	300	300
					Concrete (MPa)	-	30
					Concrete flyash %	-	average
					Rebar	-	20M
				Door Opening	Number of Doors	30	30
					Door Type	-	Steel Interior Door
			Concrete Block Wall				
				2.2.1 Wall_ConcreteBlock_P5A&B			
					Length (m)	1229	1229
					Height (m)	4	4
					Rebar	-	10M
				Door Opening	Number of Doors	118	118
					Door Type	-	Steel Interior Door
				2.2.2 Wall_ConcreteBlock_P5C			
					Length (m)	76	76
					Height (m)	4	4
					Rebar	-	10M
				Door Opening	Number of Doors	1	1
					Door Type	-	Steel Interior Door, 50% glazing
				2.2.3 Wall_ConcreteBlock_P6A-C			
					Length (m)	173	173
					Height (m)	4	4
					Rebar	-	15M
				Door Opening	Number of Doors	20	20
					Door Type	-	Steel Interior Door

Table 9 IE inputs Assumptions

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
A21 Foundation	Concrete Footing	1.2.1 Footing_F1	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.2 Footing_F2	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.3. Footing_F3	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.4 Footing_F4	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.5 Footing_F5	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.6 Footing_F6	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.7 Footing_F7	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.8 Footing_F8	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.9 Footing_F9	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.10 Footing_F10	All dimensions and rebar type were given. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.11 Footing_SF1	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff.

			Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.12 Footing_SF3	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.13 Footing_SF4	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.14 Footing_SF5	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.15 Footing_SF6	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.16 Footing_SF7	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.17 Footing_SF8	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
		1.2.18 Footing_450mm_Main Section_NorthWall	All dimensions and rebar type were given, except length which was measured using Onscreen Takeoff. Concrete was given as 25MPa but 30MPa was inputted. Flyash was assumed to be average.
	The Impact Estimator, SOG inputs are limited to being either a 100mm or 200mm thickness. Since the actual SOG thicknesses for the AERL building were not exactly 100mm or 20mm		

	thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. Lastly, the concrete stairs were modelled as footings (ie. Stairs_Concrete_TotalLength). All stairs had the same thickness and width, so the total length of stair was measured and were combined into a single input.		
A21 Lowest floor construction	Concrete Slab on Grade	1.1.5 SOG_450mm_Basement	The area of this slab had to be adjusted so that the thickness fit into the 200mm thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in meters) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(200)] = sqrt[1417m x (450))/(200)] = 56.5 meters
A22 Upper floor construction	Concrete Slab on Grade	1.1.1 SOG_150mm_GroundLevel_Middle Section1	The area of this slab had to be adjusted so that the thickness fit into the 200mm thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in meters) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(200)] = sqrt[17m x (150))/(200)] = 3.57 meters
		1.1.2 SOG_150mm_GroundLevel_Middle Section2	The area of this slab had to be adjusted so that the thickness fit into the 200mm thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in meters) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(200)] = sqrt[118m x (150))/(200)] = 9.41 meters
		1.1.3 SOG_200mm_GroundLevel_East Section	The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab;

			= sqrt[Measured Slab Area] = sqrt[(757m] = 27.51 meters
		1.1.4 SOG_200mm_GroundLevel_West Section	The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[Measured Slab Area] = sqrt[(875m] = 29.58 meters
		1.2.19 Stairs_Main East Stairwell	The thickness of the stairs was estimateded to be 237 mm and based on the cross-section structural drawings. Width was measured to be 1.277mm.
		1.2.19 Stairs_Main West Stairwell	The thickness of the stairs was estimateded to be 237 mm and based on the cross-section structural drawings. Width was measured to be 1.277mm.
	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. This being the case, in OnScreen, since no beams were present in most of the CHBE building, concrete columns were accounted for on each floor, while each floor's area was measured. The number of beams supporting each floor were assigned an average bay and span size in order to cover the measured area, as seen assumption details below for each input. Since the live loading was specified mostly as 4.8kPa, a live load of 4.8kPa on all six floors and the basement level were assumed.		
	Concrete Column	3.1.1 Column_Concrete_Beam_Concrete_GroundLevel_Main Section Lecture	Live load was assumed to be 4.8kPa. The bay size and span were measured using Onscreen Takeoff. Because the bay size limit was 12.2m, it was used in place of the measured 13.76m.
		3.1.2 Column_Concrete_Beam_N/A_GroundLEvel-Level3_MainSection	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(282m2) / (18)] = 3.96 meters
		3.1.3	Because of the variability of bay and span

		Column_Concrete_Beam_N/A_Level2_Main Section	sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(956m2) / (18)] = 7.29 meters
		3.1.4 Column_Concrete_Beam_N/A_Level3_Main Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(1032m2) / (23] = 6.70 meters
		3.1.5 Column_Concrete_Beam_N/A_Level4_Main Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(1038m2) / (34)] = 5.53 meters
		3.1.6 Column_Concrete_Beam_N/A_Level5_Main Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(1031m2) / (34] = 5.51 meters
	Steel Column	3.2.1 Column_Steel_Beam_N/A_GroundLevel_East Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(745m2) / (5)]

		= 12.2 meters
	3.2.2 Column_Steel_Beam _N/A_GroundLevel_ Main Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(594m2) / (10)] = 7.71 meters
	3.2.3 Column_Steel_Beam _N/A_GroundLevel_ West Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(871m2) / (12)] = 8.53 meters
	3.2.4 Column_Steel_Beam _N/A_Level2_East Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(754m2) / (5)] = 12.2 meters
	3.2.5 Column_Steel_Beam _N/A_Level2_West Section	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(589m2) / (10)] = 7.67 meters
The Impact Estimator calculated the thickness of the material based on floor width, span, concrete strength, concrete flyash content and live load. The only assumptions that had to be made in this assembly group were setting the live load to 4.8kPa and using a concrete strength of 30MPa.		
Concrete Suspended Slab	4.1.1 Floor_ConcreteSusp	Because of the span size was limited to 9.75m, the floor width was calculated using

		endedSlab_Level1_200mm	the following calculation; = (Measured Supported Floor Area) / (9.75) = (918m2) / (9.75) = 94.15 meters
		4.1.2 Floor_ConcreteSuspendedSlab_Level2_200mm	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Supported Floor Area) / (9.75) = (1051m2) / (9.75) = 107.8 meters
		4.1.3 Floor_ConcreteSuspendedSlab_Level2_East Section	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Supported Floor Area) / (9.75) = (763m2) / (9.75) = 78.3 meters
		4.1.4 Floor_ConcreteSuspendedSlab_Level2_ West Section	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Supported Floor Area) / (9.75) = (588m2) / (9.75) = 60.3 meters
		4.1.5 Floor_ConcreteSuspendedSlab_Level3_200mm	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Supported Floor Area) / (9.75) = (1128m2) / (9.75) = 115.7 meters
		4.1.6 Floor_ConcreteSuspendedSlab_Level4_200mm	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Floor Area) / (9.75)

			= (1132m2) / (9.75) = 116.1 meters
		4.1.7 Floor_ConcreteSuspendedSlab_Level5_200mm	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Floor Area) / (9.75) = (1124m2) / (9.75) = 115.3 meters
		4.1.8 Floor_ConcreteSuspendedSlab_Level6_200mm	Because of the span size was limited to 9.75m, the floor width was calculated using the following calculation; = (Measured Floor Area) / (9.75) = (1129m2) / (9.75) = 115.8 meters
A31 Walls below grade	Concrete cast in place	2.1.4 Wall_Cast-in-Place_W4A	Concrete was assumed to be 30MPa, flyash average, and rebar 20M. Waterproof membrane assumed to be polyethylene 6mil.
		2.1.5 Wall_Cast-in-Place_W4B	Concrete was assumed to be 30MPa, flyash average, and rebar 20M. Damp-proof membrane assumed to be polyethylene 6mil.
	Concrete block wall	2.2.6 Wall_ConcreteBlock W9	Polyethylene was assumed to be 6mil. Polystyrene expanded , 50mm, was chosen in place of 50mm duct liner.
A32 Walls above grade	Concrete cast in place	2.1.2 Wall_Cast-in-Place_W1C	Concrete was assumed to be 30MPa, flyash average, and rebar 20M. Air/vapour barrier assumed to be polyethylene 6mil. Fixed aluminum frame with standard glazing was the closest estimation to the observed windows.
		2.1.3 Wall_Cast-in-Place_W3	Concrete was assumed to be 30MPa, flyash average, and rebar 20M. Air/vapour barrier assumed to be polyethylene 6mil. Commercial steel cladding was used in place of galvalume corrugated cladding. Steel exterior door, 50% glazing was the

			closest estimtation to the observed doors in this wall.
		2.1.6 Wall_Cast-in-Place_W6	Concrete was assumed to be 30MPa, flyash average, and rebar 20M. Air/vapour barrier assumed to be polyethylene 6mil. Steel exterior door, 50% glazing was the closest estimtation to the observed doors in this wall.
	Concrete Block Wall	2.2.4 Wall_ConcreteBlock W1D	Polyethylene was assumed to be 6mil. Polystyrene expanded , 50mm, was chosen in place of 50mm spray foam insulation.
		2.2.5 Wall_ConcreteBlock W8	No air/vapour barrier was used because the wall does not fully encompass a building.
	Curtain Wall	2.3.1 Wall_CurtainWall_GlassShelter_Main Section__NorthWall	Curtain wall was used as an approximation to a glass shelter area.
		2.3.2 Wall_CurtainWall_GlassShelter_Main Section Part1	Curtain wall was used as an approximation to a glass shelter area.
		2.3.3 Wall_CurtainWall_GlassShelter_Main Section__Part2	Curtain wall was used as an approximation to a glass shelter area.
		2.3.4 Wall_CurtainWall_W16_Windows	Curtain wall was used as an approximation to a wall of windows and doors.
		2.3.5 Wall_CurtainWall_W18_Windows	
		2.3.6 Wall_CurtainWall_W6_Windows	
		2.3.7 Wall_CurtainWall_W9&W11&W12_Windows	An approximation of 60% glazing and 40% spandrel (metal) was used due to the variation of glazing to spandrel in the windows.
	Concrete Tilt Up	2.6.1 Wall_ConcreteTilt-Up W2A	Commercial steel cladding was used to approximate the addition of 92mm steel studs.
		2.6.2 Wall_ConcreteTilt-Up W2B	Commercial steel cladding was used to approximate the addition of 92mm steel studs.
		2.6.3	This wall was increased by a factor in order

		Wall_ConcreteTilt-Up_W2C	to fit the200mm thickness limitation of the Impact Estimator. This was done by increased the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/200] = (80’) * [(300”)/200] = 10 meters Commercial steel cladding was used to approximate the addition of 92mm steel studs.
B11 Partitions	Steel Stud	2.4.4 Wall_SteelStud_P2B	Since this was an interior wall, no sheathing was considered. The gypsum on both sides was assumed to be of the same specifications as the other walls (ie.1/2" Regular Gypsum). 89mm fiberglass batt was used in place of 89mm acoustic batt.
		2.4.5 Wall_SteelStud_P3	Since this was an interior wall, no sheathing was considered. The gypsum on both sides was assumed to be of the same specifications as the other walls (ie.1/2" Regular Gypsum). 89mm fiberglass batt was used in place of 89mm acoustic batt.
		2.4.6 Wall_SteelStud_P4	1/2" mousture resistant gypsum was used in place of 16mm tile backer board.
		2.4.7 Wall_SteelStud_P9	Since this was an interior wall, no sheathing was considered. The gypsum was assumed to be of the same specifications as the other walls (ie.1/2" Regular Gypsum). 89mm fiberglass batt was used in place of 89mm acoustic batt.
		2.4.8 Wall_SteelStud_F1A &B	This is a furring type of wall but approximated to be a steel stud wall by choosing 600oc so that less steel is used. 1/2" mousture resistant gypsum was used in place of 16mm tile backer board.
		2.4.9 Wall_SteelStud_F2	1/2" mousture resistant gypsum was used in place of 16mm tile backer board.
		2.4.10 Wall_SteelStud_F8	Since this was an interior wall, no sheathing was considered. The gypsum on bohth sides was assumed to be of the same

			specifications as the other walls (ie.1/2" Regular Gypsum).
		2.4.11 Wall_SteelStud_W1A	Polyethylene was assumed to be 6mil. Polystyrene expanded , 50mm, was chosen in place of 50mm spray foam insulation.
		2.4.12 Wall_SteelStud_W1B	Polyethylene was assumed to be 6mil. Polystyrene expanded , 50mm, was chosen in place of 50mm spray foam insulation.
	Wood Stud	2.5.1 Wall_WoodStud_F6	Since this was an interior wall, no sheathing was considered. This is a furring type of wall but approximated to be a wood stud wall by choosing 600oc so that less wood is used. Solid horizontal wood slats were approximated to be OSB. Polystyrene expanded , 25mm, was chosen in place of25mm acoustic insulation.
		2.5.2 Wall_WoodStud_F7	Since this was an interior wall, no sheathing was considered. This is a furring type of wall but approximated to be a wood stud wall by choosing 600oc so that less wood is used. Solid horizontal wood slats were approximated to be OSB.
	Concrete cast in place	2.1.1 Wall_Cast-in-Place_P7	Concrete was assumed to be 30MPa, flyash average, and rebar 20M. Steel interior door was the closest estimtation to the observed doors in this wall.
	Concrete Block Wall	2.2.1 Wall_ConcreteBlock_P5A&B	Steel exterior door was the closest estimtation to the observed doors in this wall.
		2.2.2 Wall_ConcreteBlock_P5C	Steel exterior door, 50% glazing was the closest estimtation to the observed doors in this wall.
		2.2.3 Wall_ConcreteBlock_P6A-C	Steel exterior door was the closest estimtation to the observed doors in this wall.
6 Extra Basic Materials	A corrugated zinc canopy could not be found in the roof assembly and therefore was approximated to be commercial steel cladding, which was the closest material to zinc.		
	6.1 Extra Materials - Cladding		
		6.1.1 XBM_Roof_CorrugatedZincCanopy_Middle Section	
			The area was found using Onscreen Takeoff. Because corrugated zinc canopy could not be found, commercial (26ga) steel cladding was the closest material to zinc canopy and was therefore used in its place.

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