Life Cycle Assessment of a MURB: Bi

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University of British Columbia

CIVIL 498E

April 1, 2012

PROVISIO

This study is part of a larger study – the UBC LCA Project – which is continually developing. As such, the findings contained in this report should be considered preliminary as there may have been subsequent refinements since the initial review of this report.

If further information is required or if you would like to use results from this please contact rob.sianchuk@gmail.com.

2012

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CIVIL 498E: Life Cycle Assessment

1/4/2012

ABSTRACT

A Life Cycle Assessment (LCA) study has been conducted on the Bi Building located on the University of British Columbia campus in Vancouver, Canada. The building is a Multi Unit Residential Building (MURB). It has been requested by the Sustainability Office at UBC.

This LCA study looks at the cradle to grave life cycle of a building and generates the environmental impact of a product system. In this case, the building is considered the product system. The main components of the life cycle of this building system include the construction products manufacturing, construction, and maintenance over the 99 year life cycle, and end of life demolition. Also included are the annual and total operating energy consumptions of the building.

The Impact Categories selected for this project are Global Warming potential, Acidification potential, Eutrophication potential, Ozone depletion potential, Photochemical Smog Potential, Human health respiratory effects potential, weighted raw resource use, and primary energy consumption.

This study is based on the ISO 14040 and 14044 standards, including the goal and scope document. Analysis is conducted on the Bill of Materials, Inventory, as well as the Building Functions. This is in addition to a Sensitivity Analysis of 5 building components. The analysis has found that of the 5 building components, the Bi building is most sensitive from an environmental impact prospective due to changes to the 20 MPa concrete with average flyash.

A major reason this study is carried out is to analyze the Fenestration Ratio from an LCA prospective. It has been found than increase in glazing results in the increase of overall environmental impact of the building system. There is however a decrease in impact during the end of life process.

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1.0 Introduction

The following Life Cycle Assessment (LCA) study is conducted on the Bi Building in UBC. It has been completed as part of the course: Civil 498E. Over the last few years, development of residential buildings at the UBC campus in Vancouver, BC has expanded at a rapid rate. A community has developed that contains low and high rise residential buildings as well as commercial buildings. Located within the community, the Bi Building is a low rise multi-unit residential building. It has 4 floors and underground parking. Contracted at over 15.75 million dollars the building was constructed less than two years to a completion date of April 16, 2008 (VanMar, 2010). It is completed under the ownership of the UBC Properties Trust. The principle architecture firm involved is, Raymond Letkeman Architects Inc.

Figure 1: Exterior of Bi Building (taken March 29th 2012)

In general, the building is wood framed construction, with underground concrete parking space. According to the UBC Residential Environmental Assessment Program (REAP), a green building rating system of residential buildings within UBC, it is certified as a bronze building (VanMar, 2010). A general summary of the building characteristics for each building system is shown below.

Building System	Specific Building Characteristics
Structure	Wood Frame Structure
Floors	Parking: Concrete Slab on Grade (SOG), Other Floors: Wood Joists
Exterior Walls	Parking: Concrete Cast in Place, Main envelope: Wood Stud Walls, Lobby: Curtain Wall
Interior Walls	Parking: Concrete Cast in Place, Other Floors: Wood Stud, and Concrete Block Assembly
Windows	Standard Glazing Windows
Roof	Wood Joist, roofing Asphalt
Mechanical	Natural Ventilation, HVAC

Table 1: Building System Characteristics

The following report, in accordance with ISO 14040 and 14044 standards, is a Life Cycle Assessment Study of the Bi building. It analyzes the cradle to grave life cycle of the building. This includes the manufacturing of building components, construction of the building, maintenance of the building over 99 years, and the end of life demolition. It is a part of a group of two other studies being conducted on two other buildings in the community. These studies are conducted around the same time and have similar requirements. Take-offs of the individual building systems (walls, floor, etc) has been conducted and the results have been input into the Athena Institute Impact Estimator Software. Through this process, the environmental Impact of the building is generated for specific Impact Categories specified by the US EPA TRACI and Athena Institute organizations. The goals and scope of this study is presented first, followed by a discussion of the Take-offs conducted. The results are then shown, including the Bill of Materials and Inventory and Sensitivity Analysis.

A major reason why this study is conducted is to analyze the Fenestration (Glazing) Ratio of the building. The analysis of changes to the fenestration ratio of the building through its life cycle is performed. As decision makers in UBC are creating more sustainable standards, a better understanding of the effects of glazing on residential buildings is required.

2.0 Goal and Scope

The following report documents the Whole Building Life Cycle Assessment of the Bi Residential building at UBC. As per ISO standards (14040 and 14044) for LCA, the intended Goal and Scope of the project is stated in this section. The intention and reasoning of the project is defined by the Goal parameters. The scope provides more detailed information regarding the modeling of the building project and how it is analyzed.

2.1 Goal

2.1.1 Intended Application

The Intended Application defines the purpose of carrying out the LCA study.

The intended application for this LCA study is as followed:

- To understanding the impact of increasing the glazing of a multi-unit residential building (MURB) over its life cycle.
- To provide a demonstration of currently accepted practice concerning the life cycle assessment of building structures with the use of the latest impact accounting methods and software.
- To contribute to a benchmark for future LCA studies of residential buildings.

2.1.2 Reason for carrying out the study

Describe the motivation of carrying out the study

The following study and report has been conducted on behalf of the UBC Civil 498E Class of 2012. This is in conjunction with UBC SEEDS, the sustainability focused program that publishes student driven reports to encourage transparent communication. It is a publically available educational asset that further promotes the use of LCA as a scientific method to determine the sustainability of a building system. This information could also be used to further inform decision making regarding the fenestration ratio standards for MURBs at UBC.

2.1.3 Intended Audience

Describe those who the LCA study is intended to be interpreted by.

Several audiences are targeted for the following study. This includes the stakeholder involved in building development within the UBC Campus. More specifically in involves the sustainability office, SEEDS, and the Residential Environmental Assessment Program. This is also intended for the building industry in general and decision makers involved in design such as: architects, engineers, developers, and building owners. General stakeholders in both private and public industries that are interested in sustainable development are also an intended audience.

2.1.4 Intended for Comparative Assertion

State whether the results of this LCA study are to be compared with the results of other LCA studies

This study is part of a group of two other studies conducted for residential buildings at UBC. These studies are compared and analyzed together. In addition to following ISO standards the studies focus on the fenestration analysis of their respective buildings. As this study is to be disclosed publically via the SEEDS website, it can be compared to external studies that follow ISO 14040 and 14044 standards.

2.2 Scope

2.2.1 Product System to be studied

Describe the collection of unit processes that will be included in the study

A unit process is defined as a measurable activity that in order to create a product or service, requires an input and output. During the lifecycle of a building system the main processes involved include Construction Product Manufacturing, Building Construction, Building Operation and Maintenance, as well as the End of Life of a building. Certain pre-construction processes, including site preparation and earthworks are not included.

When considering the construction products manufacturing phase, resources (wood, stone, etc) and energy is considered the input. Through extraction and transportation, this process outputs emissions (air, water, and land) as well as construction products.

These construction products, as well as other resources and energy is used as inputs for the Building Construction Process. Like the product manufacturing process, it outputs emissions. The building itself is also considered an output.

The next life cycle phase is building maintenance. Much like the other processes, it required resources, energy, and construction products (for replacement and repair of building components). It includes the building operation and maintenance process, as well as transportation of construction products and waste disposal.

The final process involves the end of life demolition of the building. The inputs considered include resources, energy, and the building itself. Through an equipment use and waste transportation process, the building is demolished. Outputs include the typical emissions (Air, Water, and Land) as well as the building waste products.

2.2.2 System Boundary

Details the extent of a Product System that should be studied in terms of product components, lifecycle stages, and unit processes

More specifically the report details the major components used within the building. This includes the Floors, Roofs, Wall, Columns and Beams, Slabs on grade and Footings. It also includes all associated doors, windows, and insulation, drywall, and vapour barriers. These components are considered assemblies of construction products.

2.2.3 Functions of the Product System

Describes the functions served by the product focused on in the LCA study.

The product system of focus in this LCA study is a Multi Unit Residential Building. Its main function involves providing shelter for occupants that live in Units of a certain size. A more detailed description of the Bi Building is provided in the introduction of this report

2.2.4 Functional Units

A performance characteristic of the product system being studied that will be used as a reference unit to normalize the results of the study

The following project will be analyzed based on the normalization of the LCA results through the functional units listed below:

- Per typical residential building square foot constructed (area)
- Per specific type of function (bathroom, bedroom, kitchen, parking etc) constructed
- Per typical residential building cubic foot constructed (volume)
- Per residential building occupant

More detailed discussion of the functional units as well as their application is shown in the Functions and Impact section of this report.

2.2.5 Allocation Procedures

Describes how the input and output flows of the studied product system (and unit processes within it) are distributed between it and other related product systems.

There are several ways by which an allocation problem could occur. This includes the production of more than one product, a waste treatment process that involves multiple waste products from different sources, or when materials are used (recycled or reused) in subsequent lifecycles. Input and Output flows of a product have to be allocated when these situations arise. They have to be shared amongst the products and subsequent life cycles.

A cut-off allocation method is used in this study. The impacts due to the Bi Building are allocated directly to this building. Although materials from the site could be potentially reused in the future, when the building is decommissioned, it is outside the scope of this project. It does not take into account the waste treatment processes or use in subsequent life cycles.

2.2.6 LCIA methodology and types of impact

State the methodology used to characterize the LCI results and the impact categories that will address the environmental and other issues of concern.

To characterize the life cycle impacts of the Bi Building, the Tool for the Reduction and Assessment of Chemical and other environmental Impact (TRACI) is used as primary impact assessment method. It is developed by the US Environmental Protection Agency. To characterize the Weighted Raw Resource use and Fossil Fuel consumption the impact assessment methodology developed by the Athena Institute is used.

The results are extrapolated through the Athena Impact Estimator, and ecosystem calculator. The impact categories include:

- Global warming potential – kg CO_2 equivalents
- Acidification potential – H^+ mol equivalents
- Eutrophication potential – kg N equivalents
- Ozone depletion potential – kg CFC^{-11} equivalents
- Photochemical smog potential – kg NOx equivalents
- Human health respiratory effects potential – kg $PM_{2.5}$ equivalents
- Weighted raw resource use – kg
- Fossil fuel consumption – MJ

A more detailed description of these categories is discussed in the Results and Analysis section of this report.

2.2.7 Interpretation to be used

Statement of significant issues, model evaluation results and concluding remarks.

Assumptions and Interpretation is discussed in the Building Take-Off section of the report. This includes discussions of uncertainty, sensitivity and functional units. Concluding remarks are discussed in the conclusions section.

2.2.8 Assumptions

Explicit statement of all assumptions used to by the modeler to measure, calculate or estimate information in order to complete the study of the product system.

Most assumptions occur in the material take offs and the Impact Estimator software. These are discussed further in the Building Take-off section of the report, with more detail in the Input Assumptions document in Appendix B. In general, assumptions were needed when information was missing in the drawing and documents provided to outline building characteristics. This may cause and under or overestimation of materials used. In addition, the Impact Estimator may not contain the specific components used, and materials that are closest in terms of property are inputted instead.

Assumptions regarding the software used, ATHENA Impact Estimator Version 4.1.13, are developed and built into the software by the Athena Institute. This information is proprietary and can be accessed through the ATHENA Institute webpage (Athena. 2011).

2.2.9 Value Choices and Optional Elements

Details the application and use of normalization, grouping, weighting and further data quality analysis used to better understand the LCA study results.

Due to the limited time available to complete this report, Value Choices and Optional Elements are not included in the report. There is however sufficient documentation to conduct further analysis. However, a Sensitivity analysis is conducted.

2.2.10 Limitation

Describe the extents to which the results of the modeling carried out on the product system accurately estimate the impacts created by the product system defined by the system boundary of the study.

The following limitations are to be found in the report and analysis:

System Boundary:

> Land preparation, including earth work and removal of trees is omitted from the LCA, as this information is not available. In addition impact due to reuse, recycling or treatment of waste material is outside the scope of this study

Data Sources and Assumptions:

The data is sourced fromn Architectural and Structural Drawings provided by the UBC Sustainability Office (SO). The LCA results (from Impact Estimator) include a Bill of Materials unique to the Bi Building. The life cycle inventory and characterization is based on average industry processes and impacts in the North American Construction and Product Manufacturing Industries.

2.2.11 Data Quality Requirements

Qualitative and quantitative description of the sourced data used in the study including its age, geographical and technological coverage, precision, completeness, reproducibility and uncertainty.

Several Data Sources have been used to develop the LCA study. This includes the Bill of Materials, Life cycle Inventory (LCI) flows, and characterization of LCI flows.

Bill of Materials:

The UBC SO sourced Architectural and Structural Drawings from Raymond Letkeman Architects Incorporated and Bogdonov Pao Associates respectively, and Onscreen Takeoff software is used to conduct a takeoff of building components, which are entered into the ATHENA Impact Estimator. Takeoffs are completed by members of this LCA study. As this is the case, quality of the takeoffs are dependent on human accuracy. The Bill of Materials is calculated by the Impact Estimator software, based on take-off data and component properties inputted by a member of this study. These Bill of Material results can be reproduced by inputting data from the Inputs and Assumptions documents in Appendix A and B of this report.

LCI Flows:

The source of LCI data is the Athena LCI Database. The data quality and modelling assumptions used to develop this database (built into the Impact Estimator) is outside the time and scope constraints of this report. This information is provided by the Inner Workings Transparency Document on the Athena Institute Website (Athena, 2010). The database is specific to a North American market, which creates geographic limitations. In general, LCI data include the construction product manufacturing and fuel refining and production. Construction product transportation as well as construction and demolition wastes transportation data is specific to Vancouver, British Columbia. The Athena Institute developed the LCI data and modeling parameters used in the Impact Estimator.

Characterization Factors:

As stated previously, impact categories are based on the US EPA TRACI and Athena Institute impact assessment methods. Specific documentation can be found on their respective websites, as shown in the References section of this report. In general, the characterized LCI flows are based on their potential to environmentally impact within North America. Detailed discussion of the uncertainties in the impact assessment results are in the Results section of this report.

2.2.12 Type of Critical Review

A review of the methods, data, interpretations, transparency, and consistency of the LCA study.

An ISO 14044 critical review has not been completed on this report. The report content and results have received a general review by Rob Sianchuk using a standardized grading rubric developed for the course in which this study was developed. If this report is to be used outside of intended application, it is strongly advised that the authors be included in communications.

2.2.13 Type and Format of the report required for the study

Statement of the type and format followed by the report.

The report follows an outline provided by the Instructor, Rob Sianchuk, of the LCA project course in the UBC Civil Engineering Department.

3.0 Model Development

3.1 Structure and Envelope

As stated above, the ATHENA Institute Impact Estimator software has been used to analyze the Bi Building, in terms of the Impact Categories. To perform analysis, specific building data is required. The most important of which, includes the measurements of the buildings Columns, Beams, Floors, Foundation, Footing, and Walls. Take-offs of the components has been conducted using the OnScreen Take-off software provided by UBC. Architectural, and Structural drawings, provided by, Raymond Letkeman Architects Incorporated and Bogdonov Pao Associates respectively, are feed into the OnScreen Take-off software, and using its tools accurate measurements of the components have been conducted by the individual members of this project. The following section details specific procedures used to perform the take-offs and discusses assumptions made as they relate to the drawings, and software used.

In general, detailed and clean .pdf versions of the drawing have been provide to conduct the Take-offs. Some details required by the Impact Estimator have not been found on the drawings, and careful assumptions have been made. As the building is a private residential building, access inside has not been provided. The project members however have conducted several trips to observe the exterior of the building.

Figure 2: Southeastern side of Bi

3.1.1 Columns and Beams

The Impact Estimator internally calculates the sizing of the columns and beams based on the following inputs: number of columns, number of beams, bay size, supported span, floor to floor height, and live load. The number of concrete columns and beams on each floor of the Bi residence were determined using count conditions on the structural drawings S2.1, S2.2, S2.5, S2.6, S2.7, S2.8, S2.9, S2.10, S2.11, and S2.12.

It was determined that the floors of the building were being supported by both concrete columns and wood posts. The wood posts were scattered throughout the walls, and were often a cluster of between 4 and 7 wood studs. This was an assumption because the impact estimator cannot differentiate between the different sizes of studs, or the different types of concrete columns, but rather takes the inputs provided above and calculates a appropriate size.

A Live Load of 2.4 kPa was assumed for both the concrete and softwood lumber columns. However, this was an assumption, and another assumption had to be made as to the portion of the floor space that was supported by softwood lumber posts and the portion supported by concrete columns. It was assumed that 4 wood columns can support a load equivalent to the load supported by 1 concrete column. This assumption allowed for the supported area per floor to be determined, as well as the supported area per column, bay sizes, and supported spans.

The bay sizes and supported spans were measured on the foundation level, but on subsequent levels they were calculated by determining the supported span per column, and then finding the bay size and supported span by taking the square root (which assumes the sporadic columns are spaced equally in a square pattern to support the calculated load.) However, the impact estimator requires that the bay size be within the range of 3.05m ↔ 12.2m, so in cases where the square root of the supported area per column is less than $9.3025m^2$ (3.05m x 3.05m), the bay size was stated to be the minimum (3.05m) while the supported span was adjusted so the product of the supported span and the bay size was equal to the supported area per column.

The number of columns was determined using a count condition in the impact estimator, and the beams were input as extra basic materials so a linear condition was added to account for them. Neither columns nor beams follow a pattern that is in a consistent grid format, so uncertainty was created in calculating the bill of materials assuming the columns do. The beams were measured using the linear condition and measuring the Laminated Veneer Lumber, Parallel Strand Lumber, and Fascia Beams and then using their specified dimensions to determine the volume. Certain materials had dimensions which were extremely similar (such as 1 ¾" x 9 ½" vs 1 ¾" x 9 ¼"), and these differences were unaccounted for as both were assumed to be the slightly larger dimension. Figure 3 shows a screen shot from the Onscreen Take-Off software where a count for columns and linear measurement for extra materials (LVL, Glulam beams, and Fascia) has been performed.

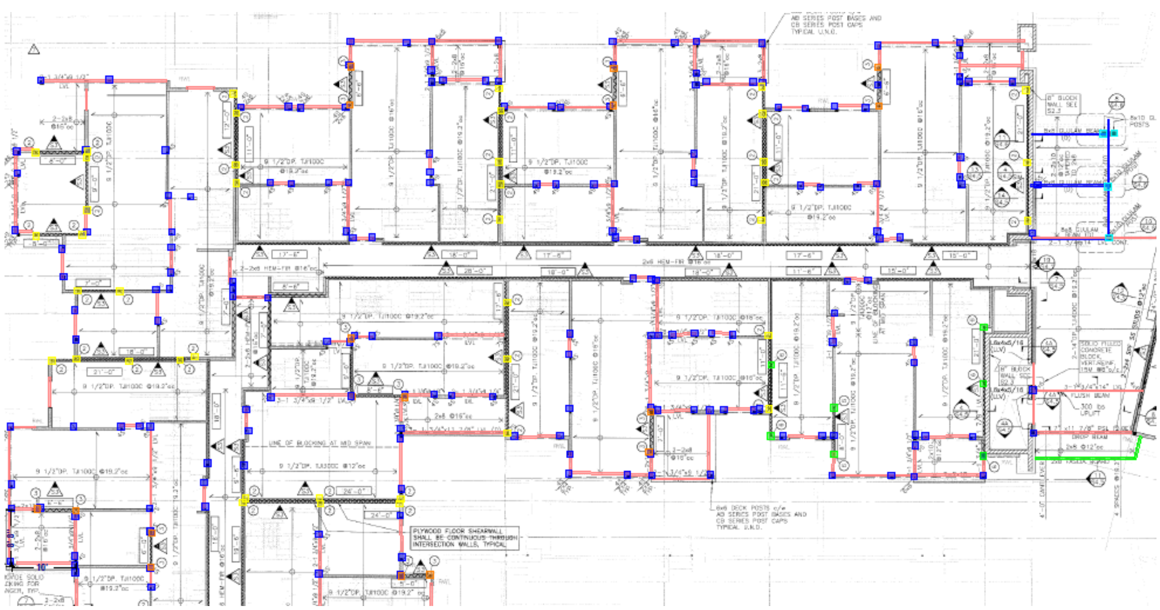

Figure 3: Second Floor Framing Over Main Floor Walls

In the roof drawings there are lines which appear to be beams, but are noted as GT (girder truss) and are not accounted for as they are a part of the roof assembly and being counted already.

This scenario is also evident in treating the wood posts as load supporting columns. The wood posts are located in the walls and often are built up around door frames, corners, and specific walls. This creates some double counting as the studs are already being accounted for in the walls assembly, but some are being double counted because they are also included in the columns count. As can be seen in Figure 4 the posts are labelled 4S (or 4 wood studs), and the LVL beams are not always consistent (one is 3 – 1 ¾" x 11 7/8" and the other is 2 - 1 ¾" x 11 7/8").

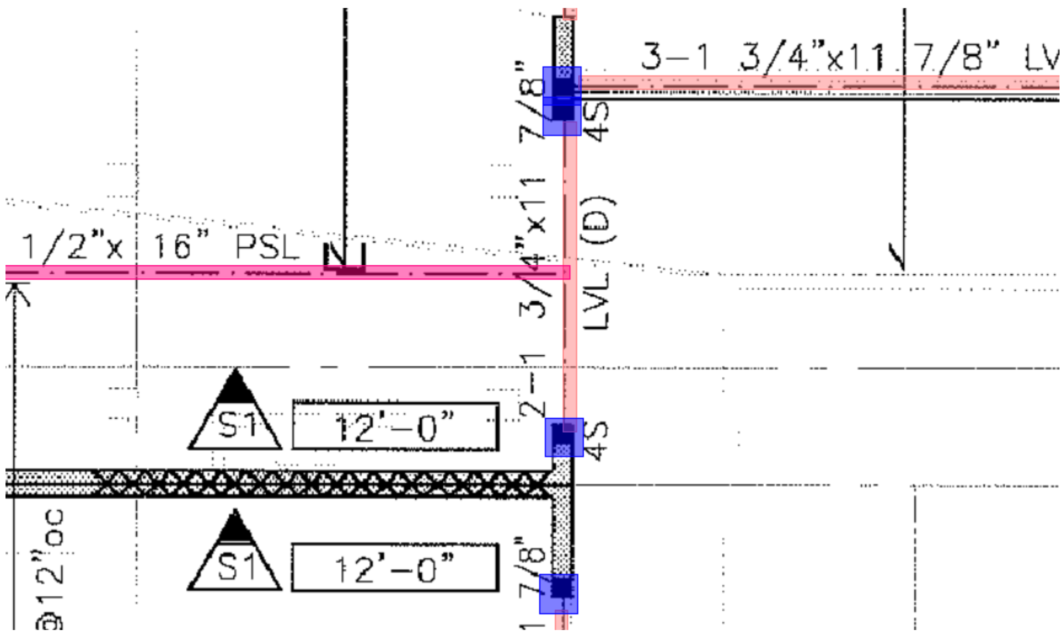

Figure 4: Roof over 4th floor framing close up analysis

3.1.2 Foundation

The foundation assembly of the Bi building is composed of concrete footings and concrete slab-on-grade. Foundation slabs were modeled using the OnScreen Takeoff by enclosing the floor plans of the foundation (drawings 66-69). The concrete footings have been named based on their types and thicknesses, where for example a twenty six-inch "A" slab was named "Footing_A_26" thickness". For the footings measured with linear conditions, all of the column footings required width adjustments to maintain the same volume of footing because the IE limits the footing thickness to be between 7.5" and 19.7". For the strip footings that had their thicknesses within the acceptable IE range, no adjustment has been made. For all the slab-on-grade, the measured areas from the OnScreen Takeoff required adjustments to be made to determine the appropriate width and length inputs for the IE to accommodate IE limitation of 4" and 8" slab thickness. A concrete strength of 4000 psi has been assumed due to IE limitation of 3000, 4000, and 9000 psi strengths. An average value of concrete flyash content has been assumed.

3.1.3Floor and Roof

All the floors of the Bi are Wood I-Joist floor type and have been modeled using OnScreen Takeoff's area condition. The floors width and span have been calculated by dividing the whole floor area into three categories: Residential, Hallway, and total floor area. Average span size of the residential and hallway areas have been measured using the OnScreen Takeoff's measuring tool. The addition of multiplication of the residential and hallway areas to their related average span size and dividing it by the total floor area would give the supported span. The width is then calculated by dividing the total floor area by the average supported span. The floors' live load was determined to be 40 psf but has been inputted as 50 psf to accommodate the IE input limitations. A Plywood decking type and 5/8" thickness has been inputted in the IE as determined in the drawings. An OSB web type and 3/8" thickness was also been set as determined in the drawings.

The roof of the Bi is a light frame wood truss. The width and span of the roof are all calculated in the same manner as the wood I-joist floors. A live load of 50 psf was inputted in the IE due to its input limitations as it was measured to be 38 psf in the structural drawings. A Pitched truss type and Plywood decking type with thickness of 5/8" has been inputted in the Impact Estimator.

3.1.4Walls

Several different wall types are within the building. In general, concrete cast in place, concrete block, and wood stud walls are found in the building. Depending on properties like height, envelope, use, and thickness, 14 Take-off conditions have been created for walls. Using a Linear Feet tool, measurements of wall length are taken. The Input Assumptions document in Appendix B details the take-offs as well as other inputs required by the Input Estimator. An important part of the wall system is the doors and windows. All doors and windows have been accounted for using the Count tool in OnScreen Take-off.

Several assumptions have been made however regarding the walls. All take-offs have been based on Architectural drawings primarily. They however do not state which walls are considered Load Bearing or Non-Load Bearing. After careful inspection of the structural drawing it is determined that most walls carry load. An assumption has been made that all walls are load bearing. Its effect of Impact estimator measurements of Bill of Materials is minimal, but is overestimated. Interior Partition Walls from the Main Floor to the 3rd floor have 2 -2x4 studs at 12" OC. The minimal OC option in IE is 16" OC. It is therefore assumed that this wall type is 16" OC. This causes a reduction in the plywood in the building, which somewhat compensates for the extra plywood due to considering all walls load bearing.

In term of materials within the wall envelope, Acoustic Insulation is considered Fiberglass BATT insulation. Insulation thickness is based on the Take-off of wall cross sections. The concrete walls have strength of 3600 psi. Due to unavailability of option in IE, this value is considered to be 4000 psi. Door properties are based on the Door Schedule provided. Since windows can only be considered fixed or operable within one wall condition, it is assumed that all windows are operable. This increases the amount of materials. The only Door input available in IE is for doors of a standard size (32"x7"). In this project however, all standard doors are larger. Therefore, doors are assumed to be 32”x7” and double doors are counted twice.

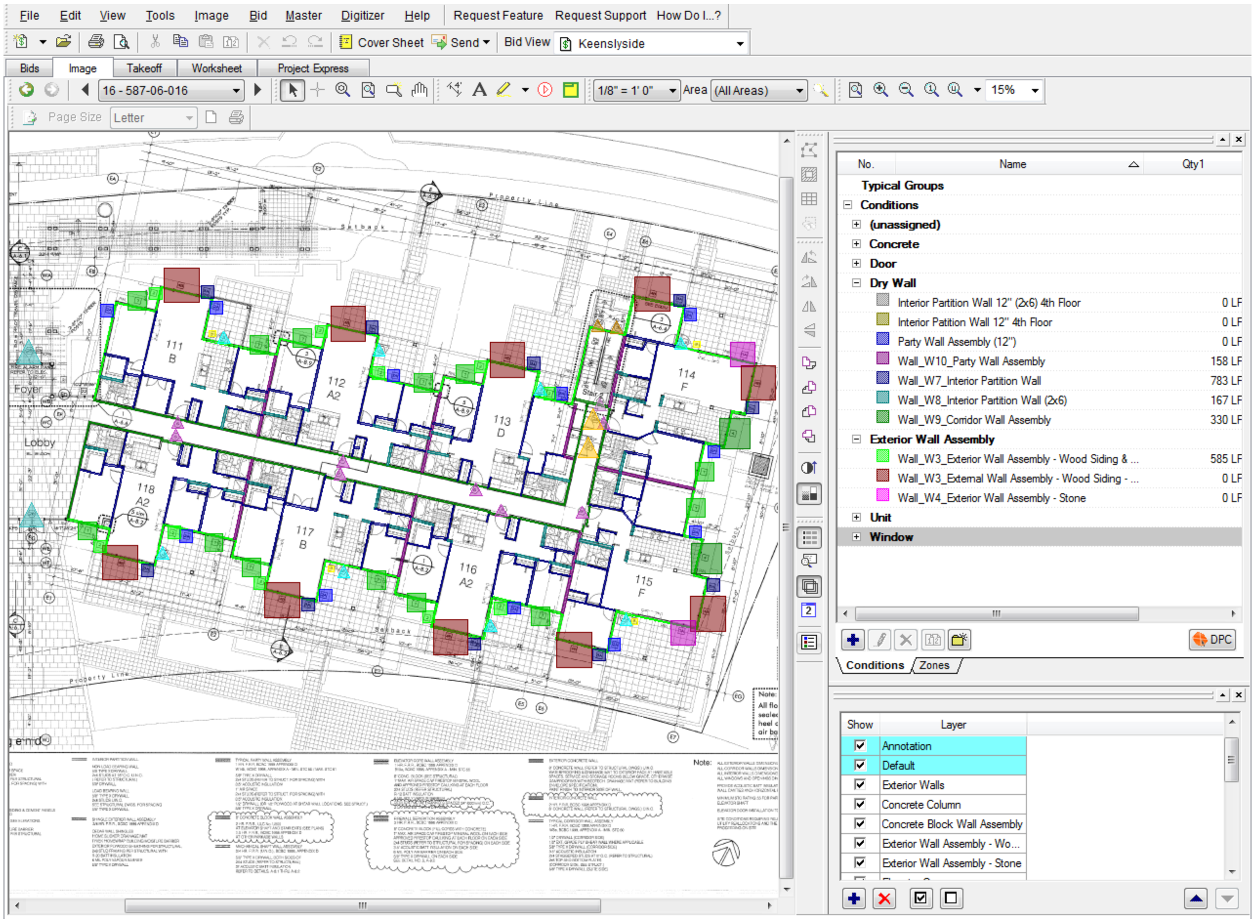

Figure 5: Typical Wall Take-off

3.2 Use Phase

Energy is consumed on an annual basis by the building through its life cycle. This is noted as part of the basic building information required by the Athena Impact Estimator. This information has been provided by the Sustainability Office, in the form of electrical and fossil fuel consumption. These values were also related to the fenestration ratio of the building, and provided as energy use per floor area. The Bi Building with a fenestration ratio of approximately 30% uses 493,987.63 kwh/year of electrical energy. This is in addition to 62,409.37 m^3/year of natural gas. It is assumed that theses values present an average year. No other energy inputs are provided and are therefore not included as part of the operating energy consumption of the building.

4.0 Results and Interpretation

The following section details the main results generated by the Impact Estimator, on the building. As part of the Inventory Analysis, a Bill of Materials is presented in addition, to an energy use profile per year and over the life of the building. Within the Impact Assessment section, the Impact Category results are presented. Uncertainty within the summary measure results is also discussed. A sensitivity analysis is also performed, by increasing the amount of significant materials, detailed in the Bill of Materials section, by 10%. A chain of custody inquiry is conducted regarding the insulation used in the building. Finally the building functions are discussed, and the Functional Units are applied to the results

4.1 Inventory Analysis

4.1.2 Bill of Materials

The following section of the report details the Bill of Materials used to construct the Bi Building. The list is generated by the Athena Impact Estimator. The data located in the Inputs document (Appendix A) is input into the Impact Estimator, which estimates the types of materials that are used in the building, as well as their quantities. This list is shown below. It shows the materials used within each Assembly Group as well as the whole building.

		Assembly Group						
Construction Material	**Units**	**Foundation**	**Walls**	**Floors**	**Columns & Beams**	**Roof**	**Extra Basic Material**	**Building Total**
#15 Organic Felt	m2		981.1851			21507.729		22488.9141
1/2" Regular Gypsum Board	m2		3898.9077					3898.9077
5/8" Fire-Rated Type X Gypsum Board	m2		25237.893					25237.893
5/8" Gypsum Fiber Gypsum Board	m2			13805.1212		1743.9131		15549.0343
6 mil Polyethylene	m2	2570.6034	3546.5415			1681.7663		7798.9113
Aluminum	Tonnes		45.3441					45.3441
Ballast (aggregate stone)	Kg					176597.0464		176597.0464
Batt. Fiberglass	m2 (25mm)		37661.6626	22673.9324		23944.0364		84279.6313
Cedar Wood Bevel Siding	m2		14916.0966					14916.0966
Cold Rolled Sheet	Tonnes		0.0292					0.0292
Concrete 20 MPa (flyash av)	m3						1841.175	1841.175
Concrete 30 MPa (flyash av)	m3	592.8977	339.8385		214.267			1147.0032
Concrete Blocks	Blocks		3920.0599					3920.0599
EPDM membrane (black, 60 mil)	Kg		10391.803					10391.803
Expanded Polystyrene	m2 (25mm)		155.19					155.19

Foam Polyisocyanurate	m2 (25mm)	1403.1783						1403.1783
Galvanized Sheet	Tonnes		4.6651	5.4474		2.6897		12.8022
Glazing Panel	Tonnes		16.6815					16.6815
GluLam Sections	m3						0.7245	0.7245
Joint Compound	Tonnes		29.0791	13.7778		1.7405		44.5973
Laminated Veneer Lumber	m3			50.5757			43.6626	94.2382
Large Dimension Softwood Lumber, kiln-dried	m3						5.3436	5.3436
Mortar	m3		76.8879					76.8879
Nails	Tonnes	0.0237	13.7371	1.8744		1.0941		16.7293
Natural Stone	m2		151.8825					151.8825
Oriented Strand Board	m2 (9mm)			1889.183				1889.183
Paper Tape	Tonnes		0.3337	0.1581		0.02		0.5119
Parallel Strand Lumber	m3						0.2311	0.2311
Rebar, Rod, Light Sections	Tonnes	3.7057	28.36		102.1352			134.2008
Roofing Asphalt	Kg					117324.6142		117324.6142
Screws Nuts & Bolts	Tonnes		4.8796					4.8796
Small Dimension Softwood Lumber, Green	m3		65.949					65.949
Small Dimension Softwood Lumber, kiln-dried	m3		596.6477	42.7166	77.4908	34.437		751.292
Softwood Plywood	m2 (9mm)		5853.482	10403.3808		2102.7086		18359.5714
Solvent Based Alkyd Paint	L		18.2098					18.2098
Standard Glazing	m2		9818.1776					9818.1776
Type III Glass Felt	m2					43015.458		43015.458
Water Based Latex Paint	L		8404.4333					8404.4333
Welded Wire Mesh / Ladder Wire	Tonnes	2.19						2.19

Table 2: Bill of Materials – Summary

Due to its use in a majority of wall and floor systems, BATT Fiberglass insulation is a material of interest within this building. It is an envelope component in walls, floors, and roof assembly groups. There is approximately 84,280 m^2 of 25 mm BATT Fiberglass used for the most part; R-

12, R-20, and acoustic insulation have been used in this project according to drawings provided. Due to lack of options within the Athena Impact Estimator, they are all assumed to be BATT Fiberglass insulation. Based on take-offs of wall cross-sections their individual thickness is determined

In terms of weight, a major component is Concrete 20 MPa (with average flyash). For all the Wood I-Joist floors there is 1 ½" concrete topping that are inputted as an extra basic material. To find the volume of the total concrete topping, the total area of the second, third, and fourth floor were measured and calculated by multiplying it to the concrete topping thickness. The concrete strength is inputted as 20 MPa as indicated in the structural drawings. The Impact Estimator has assumed an average flyash content for the concrete topping.

Reinforced Rebar is a major part of several assemblies in this building. In general all concrete cast in place structures contain rebar. This includes the concrete walls, foundation, and columns. In wall assemblies, since rebar type is not specified, it is assumed that #5 rebar is used. This is also the case when it comes to columns, as well as the foundation.

As this is a wood frame building for the most part, there is significant usage of Softwood Plywood. It is used as wood studs in most types of walls, as well as part of the wood joist within the floors. Several wood post columns are also found in the building. As stated in the take-off assumptions section of this report, all walls are considered load bearing, which overestimates the amount of softwood plywood. In addition, interior partition walls on the main and second floor have wood studs that are 12" on center. Since the Impact Estimator can only specify to 16" on center, this is inputted. Due to this change there is also and underestimation of softwood plywood used.

Drywall is used mostly in the walls, and floor. Of the different drywall types that make up a major part of this building, 5/8" regular Gypsum Board is used the most. It is used in the floors and roof system of the building. For the most part, assumptions have not been made for this specific envelope material.

4.1.2 Energy Use

Shown below is the summary of the total Energy Consumption model for the Bi Building through its lifecycle. Of particular interest is the Operating Energy of the building. An annual and total energy value is given. It is assumed that the building has a service life of 99 years.

Energy Type	**Manufacturing**	**Construction**	**Maintenance**	**End of Life**	**Operating Energy**		
	Total	Total	Total	Total	Annual	Total	Total
Electricity kWh	554708.2062	12084.80381	349876.1543	0	493987.6	48904775	49821445
Hydro MJ	1760625.317	43384.61706	2367509.094	415.6221127	1757082	1.74E+08	1.78E+08
Coal MJ	1837103.701	6708.242534	1033061.924	6064.894732	35759	3540141	6423079
Diesel MJ	1542528.863	1335801.488	922326.3212	902122.9986	35219.32	3486713	8189492
Feedstock MJ	3147689.793	0	6406757.196	0	0	0	9554447

Gasoline MJ	20407.62293	0	52715.04996	0	0	0	73122.67
Heavy Fuel Oil MJ	1180737.183	19656.89532	598920.6107	20080.05821	2655.098	262854.7	2082249
LPG MJ	11537.34793	893.0218897	16956.72745	905.0508825	1097.625	108664.8	138957
Natural Gas MJ	7472347.792	43690.10276	2848136.013	36957.47738	2890674	2.86E+08	2.97E+08
Nuclear MJ	11909371.48	1822.115101	55907115.47	1553.501171	11214.28	1110214	68930076
Wood MJ	868151.4694	0	280060.0008	0	0	0	1148211
Total Primary Energy Consumption MJ	29750500.57	1451956.482	70433558.41	968099.6031	4733701	4.69E+08	5.71E+08

Table 3: Energy Consumption values for Building Life Cycle.

4.2 Impact Assessment

The following section of this report details the Impact results of the building through its life cycle stages. The results are split into the major assembly groups, including the foundation, walls, floors, columns & beams, roof, and extra basic material. The subsections detailed each Impact Category chosen for the project, as stated in the Goals and Scope. They are based on TRACI (TRACI, 2012) and the Athena Institute characterizations.

4.2.1Global Warming Potential

Global Warming occurs due to heat being trapped within the earth's atmosphere. This is due to a buildup of chemicals in the atmosphere. This impact category refers to the potential buildup of air emissions (characterized as Carbon Dioxide equivalents) that cause Global Warming. Shown below is a summary of global warming potential impact due to each building component during the life cycle of this building.

Life Cycle Stage	Process	Impact Category	Assembly Group						
		Global Warming Potential	Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	kg CO2 eq	177428.1912	392652.507	127346.3586	119236.7564	54354.13531	367991.6489	1239009.597
	Transportation	kg CO2 eq	4933.787713	17443.8093	7740.66415	4173.688758	1638.558774	13278.10869	49208.6174
	Total	kg CO2 eq	182361.9789	410096.316	135087.0227	123410.4451	55992.69408	381269.7576	1288218.214
Construction	Site Preparation	kg CO2 eq							
	Material	kg CO2 eq	7671.265704	8328.67688	554.2226024	32.34112069	652.4520512	0	17238.95836
	Transportation	kg CO2 eq	7621.240626	21674.6431	9633.677474	4155.737072	3291.23721	22451.72431	68828.2598
	Total	kg CO2 eq	15292.50633	30003.32	10187.90008	4188.078193	3943.689261	22451.72431	86067.21816
Maintenance	Material	kg CO2 eq	0	499501.504	0	0	61514.52925	0	561016.0331
	Transportation	kg CO2 eq	0	26422.4792	0	0	3851.194813	0	30273.67401
	Total	kg CO2 eq	0	525923.983	0	0	65365.72406	0	591289.7071
End-of-Life	Material	kg CO2 eq	4265.127577	11939.198	6069.157767	3638.124142	1321.030367	14492.0569	41724.69477
	Transportation	kg CO2 eq	3585.230395	5722.51154	1693.427566	1673.136833	647.2756069	11088.92238	24410.50433
	Total	kg CO2 eq	7850.357971	17661.7096	7762.585333	5311.260976	1968.305974	25580.97929	66135.1991
Operating Energy	Annual	kg CO2 eq	166923.7924	166923.792	166923.7924	166923.7924	166923.7924	166923.7924	166923.7924
	Total	kg CO2 eq	16525455.44	16525455.4	16525455.44	16525455.44	16525455.44	16525455.44	16525455.44

Table 5: Global Warming potential – Summary of Impact Results during Life Cycle of each assembly group.

4.2.2 Ozone Layer Depletion

In TRACI, the following impact category refers to the destruction of the Ozone Layer due to chemical substances such as CFC. The category indicator for Ozone Layer Depletion is “kg CFC-11 eq”, and the summarized results are as shown below.

Life Cycle Stage	Process	Impact Category	Assembly Group						
		Ozone Layer Depletion	Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	kg CFC-11 eq	0.000337879	0.000444434	4.6552E-06	0.000121722	4.26869E-06	0.000714231	0.001627189
	Transportation	kg CFC-11 eq	2.07439E-07	7.31764E-07	3.19988E-07	1.73049E-07	6.75668E-08	5.55241E-07	2.05505E-06
	Total	kg CFC-11 eq	0.000338086	0.000445166	4.97519E-06	0.000121895	4.33626E-06	0.000714786	0.001629244
Construction	Site Preparation	kg CFC-11 eq							
	Material	kg CFC-11 eq	0	1.02897E-09	0	1.5669E-11	3.35993E-10	0	1.38063E-09
	Transportation	kg CFC-11 eq	3.12283E-07	8.88015E-07	4.09521E-07	1.70208E-07	1.36798E-07	9.19779E-07	2.8366E-06
	Total	kg CFC-11 eq	3.12283E-07	8.89044E-07	4.09521E-07	1.70224E-07	1.37134E-07	9.19779E-07	2.83798E-06
Maintenance	Material	kg CFC-11 eq	0	0.000910585	0	0	5.10321E-07	0	0.000911095
	Transportation	kg CFC-11 eq	0	1.08361E-06	0	0	1.57918E-07	0	1.24153E-06
	Total	kg CFC-11 eq	0	0.000911669	0	0	6.68239E-07	0	0.000912337
End-of-Life	Material	kg CFC-11 eq	1.9215E-07	5.37878E-07	2.73424E-07	1.63903E-07	5.95143E-08	6.52888E-07	1.87976E-06
	Transportation	kg CFC-11 eq	1.46842E-07	2.34379E-07	6.93585E-08	6.85274E-08	2.65108E-08	4.54174E-07	9.99792E-07
	Total	kg CFC-11 eq	3.38992E-07	7.72258E-07	3.42783E-07	2.3243E-07	8.60251E-08	1.10706E-06	2.87955E-06
Operating Energy	Annual	kg CFC-11 eq	1.18747E-07	1.18747E-07	1.18747E-07	1.18747E-07	1.18747E-07	1.18747E-07	1.18747E-07
	Total	kg CFC-11 eq	0.000011756	0.000011756	0.000011756	0.000011756	0.000011756	1.1756E-05	0.000011756

Table 6: Ozone Layer Depletion – Summary of Impact Results during Life Cycle of each assembly group.

4.2.3 Acidification Potential

Acidification Potential is defined as the potential for the increase in total acidity through the emission of substances (measured in moles of Hydrogen ion equivalents) within soil and water systems. This may be caused by chemical substances such as nitrogen oxides (NO_2) and sulfur dioxide (SO_2) being emitted from process activities. Its impact on this building is shown below.

Life Cycle Stage	Process	Impact Category	Assembly Group						
		Acidification Potential	Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	moles of H+ eq	59693.3839	171596.131	45577.30433	41590.42405	19996.47968	124759.1295	463212.8525
	Transportation	moles of H+ eq	2097.732402	7200.941762	2704.365545	1527.493026	560.833314	5344.342217	19435.70827
	Total	moles of H+ eq	61791.1163	178797.0727	48281.66988	43117.91707	20557.31299	130103.4718	482648.5607
Construction	Site Preparation	moles of H+ eq							
	Material	moles of H+ eq	3968.856311	4439.347261	325.1092266	18.26664235	355.7338996	0	9107.313341
	Transportation	moles of H+ eq	2443.523122	6916.92173	7412.48912	1310.702091	1622.284679	7143.424601	26849.34534
	Total	moles of H+ eq	6412.379433	11356.26899	7737.598347	1328.968733	1978.018579	7143.424601	35956.65868
Maintenance	Material	moles of H+ eq	0	330026.436	0	0	23460.39395	0	353486.83
	Transportation	moles of H+ eq	0	8525.483444	0	0	1251.373346	0	9776.856791
	Total	moles of H+ eq	0	338551.9195	0	0	24711.76729	0	363263.6868
End-of-Life	Material	moles of H+ eq	236.4669763	661.9323815	336.4859222	201.7046853	73.24049536	803.4678483	2313.298309
	Transportation	moles of H+ eq	1130.760433	1804.846249	534.097025	527.6974482	204.146893	3497.380447	7698.928495
	Total	moles of H+ eq	1367.22741	2466.77863	870.5829472	729.4021334	277.3873883	4300.848295	10012.2268
Operating Energy	Annual	moles of H+ eq	69746.28053	69746.28053	69746.28053	69746.28053	69746.28053	69746.28053	69746.28053
	Total	moles of H+ eq	6904881.772	6904881.772	6904881.772	6904881.772	6904881.772	6904881.772	6904881.772

Table 7: Acidification Potential – Summary of Impact Results during Life Cycle of each assembly group.

4.2.4 Eutrophication Potential

Air and Water Emissions have the potential to contribute to the impairment of water bodies. This is defined as Eutrophication. Many chemicals such as phosphorus, nitrogen dioxide, nitric oxide, nitrogen and ammonium can contribute to Eutrophication. It is expressed in terms of kilograms of Nitrogen released.

Life Cycle Stage	Process	Impact Category Eutrophication Potential	Assembly Group						
			Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	kg N eq	46.36025308	138.1424009	30.27241356	155.7415631	11.05294807	86.12633381	467.6959125
	Transportation	kg N eq	2.210501751	7.576904619	2.819584875	1.596927973	0.584009012	5.616193898	20.40412213
	Total	kg N eq	48.57075483	145.7193056	33.09199844	157.338491	11.63695708	91.74252771	488.1000347
Construction	Site Preparation	kg N eq							
	Material	kg N eq	3.889629175	3.52683664	0.120426951	0.005021515	0.142254765	0	7.684169047
	Transportation	kg N eq	2.534031378	7.170888985	7.98539014	1.357752514	1.721501032	7.404219012	28.17378306
	Total	kg N eq	6.423660554	10.69772563	8.105817091	1.362774029	1.863755797	7.404219012	35.85795211
Maintenance	Material	kg N eq	0	143.5447608	0	0	3.541058568	0	147.0858193
	Transportation	kg N eq	0	8.844873731	0	0	1.298861324	0	10.14373506
	Total	kg N eq	0	152.3896345	0	0	4.839919893	0	157.2295544
End-of-Life	Material	kg N eq	0.162365088	0.454501981	0.231040998	0.13849629	0.050289049	0.551684339	1.588377745
	Transportation	kg N eq	1.068266724	1.705097855	0.504579098	0.498533206	0.192864312	3.304090806	7.273431999
	Total	kg N eq	1.230631811	2.159599835	0.735620096	0.637029496	0.243153361	3.855775145	8.861809744
Operating Energy	Annual	kg N eq	6.696843335	6.696843335	6.696843335	6.696843335	6.696843335	6.696843335	6.696843335
	Total	kg N eq	662.9874902	662.9874902	662.9874902	662.9874902	662.9874902	662.9874902	662.9874902

Table 8: Eutrophication Potential – Summary of Impact Results during Life Cycle of each assembly group.

4.2.5 Smog Potential

Volatile organic compounds (VOC) or emissions like NO_x have the potential to help create smog. It is measured in terms of kilograms of NO_x created during the life cycle processes.

Life Cycle Stage	Process	Impact Category Smog Potential	Assembly Group						
			Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	kg NOx eq	856.313209	1434.974559	188.183746	441.7224757	124.1880238	1802.782825	4848.164839
	Transportation	kg NOx eq	48.46307219	165.9264822	61.19456727	34.73475372	12.6531598	122.7852421	445.7572772
	Total	kg NOx eq	904.7762811	1600.901041	249.3783133	476.4572294	136.8411836	1925.568067	5293.922116
Construction	Site Preparation	kg NOx eq							
	Material	kg NOx eq	95.42418835	87.05875109	2.854650593	0.113986786	3.331807985	0	188.7833848
	Transportation	kg NOx eq	54.63143358	154.5714928	175.6821239	29.25422436	37.57621566	159.5834197	611.29891
	Total	kg NOx eq	150.0556219	241.6302439	178.5367745	29.36821115	40.90802365	159.5834197	800.0822948
Maintenance	Material	kg NOx eq	0	2361.631585	0	0	226.5573936	0	2588.188979
	Transportation	kg NOx eq	0	190.8149472	0	0	28.02211609	0	218.8370633
	Total	kg NOx eq	0	2552.446532	0	0	254.5795097	0	2807.026042
End-of-Life	Material	kg NOx eq	3.038502421	8.505556145	4.323704329	2.59182142	0.941109942	10.3242281	29.72492236
	Transportation	kg NOx eq	25.23799523	40.28324629	11.92077276	11.77793747	4.556454365	78.05974497	171.8361511
	Total	kg NOx eq	28.27649765	48.78880243	16.24447709	14.3697589	5.497564307	88.38397308	201.5610735
Operating Energy	Annual	kg NOx eq	65.43917117	65.43917117	65.43917117	65.43917117	65.43917117	65.43917117	65.43917117
	Total	kg NOx eq	6478.477946	6478.477946	6478.477946	6478.477946	6478.477946	6478.477946	6478.477946

Table 9: Smog Potential – Summary of Impact Results during Life Cycle of each assembly group.

4.2.6 Human Health Respiratory Effects

Particulate matter formed from emissions of gases such as sulfur dioxide and VOCs, are associated with disturbance of the human respiratory system. While coarser particles can create some problems within the respiratory system, such as asthma, finer particles ($PM_{2.5}$) are associated with more serious problems, like chronic bronchitis. For this reason, Human Health Respiratory Effects are expressed as kilograms of $PM_{2.5}$ equivalents as per TRACI.

Life Cycle Stage	Process	Impact Category Human Health Respiratory Effects	Assembly Group Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	kg PM2.5 eq	395.7158866	1952.001398	466.0186594	227.8414683	329.1183741	918.082014	4288.777801
	Transportation	kg PM2.5 eq	2.548777701	8.741026541	3.263509432	1.846529333	0.676253016	6.482004527	23.55810055
	Total	kg PM2.5 eq	398.2646643	1960.742425	469.2821689	229.6879977	329.7946271	924.5640185	4312.335901
Construction	Site Preparation	kg PM2.5 eq							
	Material	kg PM2.5 eq	4.407582173	4.682462427	0.136463313	0.016136206	0.385194566	0	9.627838686
	Transportation	kg PM2.5 eq	2.938620132	8.316756578	9.1338046	1.575169567	1.979762811	8.588003351	32.53211704
	Total	kg PM2.5 eq	7.346202305	12.99921901	9.270267912	1.591305773	2.364957378	8.588003351	42.15995572
Maintenance	Material	kg PM2.5 eq	0	4930.33827	0	0	327.931613	0	5258.269883
	Transportation	kg PM2.5 eq	0	10.25558245	0	0	1.505761502	0	11.76134395
	Total	kg PM2.5 eq	0	4940.593852	0	0	329.4373745	0	5270.031227
End-of-Life	Material	kg PM2.5 eq	0.225112817	0.630149145	0.320329269	0.192019666	0.069723792	0.764888668	2.202223357
	Transportation	kg PM2.5 eq	1.358919785	2.169019364	0.64186453	0.634173678	0.245338662	4.203064897	9.252380916
	Total	kg PM2.5 eq	1.584032602	2.799168509	0.9621938	0.826193344	0.315062454	4.967953565	11.45460427
Operating Energy	Annual	kg PM2.5 eq	328.8305577	328.8305577	328.8305577	328.8305577	328.8305577	328.8305577	328.8305577
	Total	kg PM2.5 eq	32554.22521	32554.22521	32554.22521	32554.22521	32554.22521	32554.22521	32554.22521

Table 10: Human Health Respiratory Effects – Summary of Impact Results during Life Cycle of each assembly group.

4.2.7 Weighted Resource Use

Resources have been used as inputs for the unit processes of the building. This includes many types of resources such as wood, iron ore, stone, and much more. The extraction of these resources are ranked in terms of their ecological carrying capacity, and characterized in terms of kg extracted. This method was developed by the Athena Sustainable Materials Institute. They are converted to a Weighted Resource Use based on the relative impact due to their extraction.

Life Cycle Stage	Process	Impact Category Weighted Resource Use	Assembly Group Foundation	Walls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	ecologically weighted kg	1573005.28	2222625.803	703989.3344	812009.7859	221891.4272	4734036.286	10267557.92
	Transportation	ecologically weighted kg	2041.342849	7745.481319	2834.780134	1500.889204	579.4312683	5225.02273	19926.9475
	Total	ecologically weighted kg	1575046.623	2230371.285	706824.1146	813510.6751	222470.8584	4739261.309	10287484.86
Construction	Site Preparation	ecologically weighted kg							
	Material	ecologically weighted kg	2640.182094	2283.804061	231.9318211	2.402755501	51.52296345	0	5209.843695
	Transportation	ecologically weighted kg	2446.102078	6918.234759	8219.145052	1308.074191	1728.761761	7140.793245	27761.11109
	Total	ecologically weighted kg	5086.284172	9202.03882	8451.076873	1310.476947	1780.284725	7140.793245	32970.95478
Maintenance	Material	ecologically weighted kg	0	928572.0037	0	0	313854.8156	0	1242426.819
	Transportation	ecologically weighted kg	0	8498.197513	0	0	1251.86324	0	9750.060752
	Total	ecologically weighted kg	0	937070.2012	0	0	315106.6789	0	1252176.88
End-of-Life	Material	ecologically weighted kg	1540.513693	4312.297275	2192.108085	1314.04746	477.140562	5234.359747	15070.46682
	Transportation	ecologically weighted kg	1128.501609	1801.24086	533.0301045	526.6433116	203.739086	3490.394025	7683.548996
	Total	ecologically weighted kg	2669.015302	6113.538135	2725.13819	1840.690771	680.879648	8724.753772	22754.01582
Operating Energy	Annual	ecologically weighted kg	57550.38834	57550.38834	57550.38834	57550.38834	57550.38834	57550.38834	57550.38834
	Total	ecologically weighted kg	5697488.446	5697488.446	5697488.446	5697488.446	5697488.446	5697488.446	5697488.446

Table 11: Weighted Resource Use – Summary of Impact Results during Life Cycle of each assembly group.

4.2.8 Fossil Fuel Use

Fossil Fuel is a major input for the unit processes involved. It is calculated based on the total fossil fuel energy (MJ) consumed during the various life cycle stages and unit processes of the Bi Residential Building.

Life Cycle Stage	Process	Impact Category	Assembly Group						
		Fossil Fuel Use	Foundation	Valls	Floors	Columns & Beams	Roof	Extra material	Building Total
Manufacturing	Material	MJ	1178980.567	4732940.262	2029195.539	1983445.567	2020952.162	2416791.997	14362306.09
	Transportation	MJ	87106.64092	330933.3211	120713.5594	63879.74324	24654.18983	222758.7557	850046.2101
	Total	MJ	1266087.208	5063873.583	2149909.098	2047325.31	2045606.352	2639550.753	15212352.3
Construction	Site Preparation	MJ							
	Material	MJ	113906.5797	98158.97472	10006.34029	97.99500877	2101.334594	0	224271.2243
	Transportation	MJ	103847.2559	293681.5248	352466.6198	55515.49298	73856.05515	303111.5773	1182478.526
	Total	MJ	217753.8355	391840.4995	362472.9601	55613.48799	75957.38974	303111.5773	1406749.75
Maintenance	Material	MJ	0	5076424.619	0	0	6388469.625	0	11464894.24
	Transportation	MJ	0	360820.2029	0	0	53159.39583	0	413979.5987
	Total	MJ	0	5437244.822	0	0	6441629.02	0	11878873.84
End-of-Life	Material	MJ	65424.90933	183141.2856	93097.82404	55806.99238	20263.94063	222300.8555	640035.8075
	Transportation	MJ	47894.32104	76445.79977	22622.1343	22351.07477	8646.815491	148134.527	326094.6724
	Total	MJ	113319.2304	259587.0854	115719.9583	78158.06715	28910.75612	370435.3825	966130.4798
Operating Energy	Annual	MJ	2965405.188	2965405.188	2965405.188	2965405.188	2965405.188	2965405.188	2965405.188
	Total	MJ	293575113.6	293575113.6	293575113.6	293575113.6	293575113.6	293575113.6	293575113.6

Table 12: Fossil Fuel Use – Summary of Impact Results during Life Cycle of each assembly group.

4.3 Uncertainty

Due to the complex nature of impact assessment within this LCA study, there are a few uncertainties and assumptions involved. They can affect the results of this study, and are therefore discussed in this section.

In general, there is uncertainty involved with the Data, Model, Temporal Variability and Spatial variability. Several unknowns exist that may cause Data Uncertainty. The service life of the building is assumed to be 99 years, but the actual value is not known. Transportation data is based on a regional average and the travel potential of emissions are not accounted.

The report is limited to the impact categories stated in the goal and scope. For this reason, only a limited amount of impacts are analyzed and complete assessments of all potential issues are not discussed. The Potential impacts not included may be specific to the Vancouver region. Furthermore, impacts are not discussed from an aesthetic, political, or economic view.

Temporal Variability within Impact Assessments can be caused by the interpretation of impacts over time. Since there is high variability within impacts, the element of time may create uncertainty. Changes in the temperature and general climate may affect the impact of this building.

In terms of Spatial Variability, the impacts of concern can be grouped in a regional way. Global Warming and ozone depletion are global effects, while acidification, smog and eutrophication happens on a regional level. A North American average is used to characterize theses effectives, even if they may be sensitive to certain regions. In a similar note, emission distribution patterns are also affected by the location.

Finally, uncertainty can be created due to variability between object and source. The impact of emissions on humans is dependent on emissions patterns. For example, the building is constructed at an area with a relatively low human density. This is not taken into account in the Impact Estimation.

4.4 Sensitivity Analysis

A Sensitivity analysis allows for the results to be interpreted and enables a better understanding of how each material affects the overall building impact.

Five analyses are performed where the amount of the material being analysed is increased by 10% in the Impact estimator. The Primary Energy Consumption, Weighted Resource Use, Global Warming Potential, Acidification Potential, HH Respiratory Effects Potential, Eutrophication Potential, Ozone Depletion Potential, and Smog Potential were all considered and how their value is influenced by varying each material quantity.

The relationship between these inputs and outputs are assumed to be linear, and the data can be expanded on to determine how a 20% change in material use would influence the outputs, or how a 40% decrease would influence the outputs.

The Batt Fiberglass insulation appears to impact the HH Respiratory Effects potential slightly, but it also slightly affects the overall Global Warming Potential, Primary Energy consumption, and Acidification Potential. However, these latter values are less than 0.5% so they have relatively little effect overall.

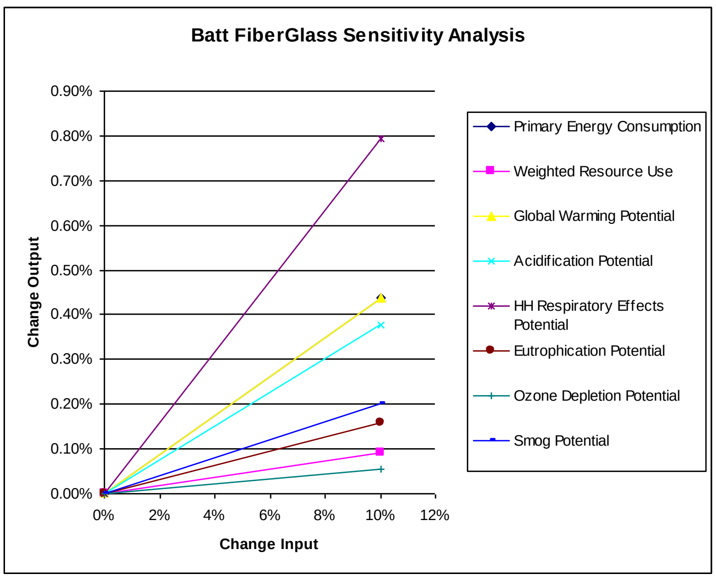

Figure 6: Batt Fiberglass Sensitivity Analysis

The Concrete 20 MPa (flyash av) has a relatively large influence of 4% on the weighted resource use, as well as many other factors as seen in the chart above. Ozone depletion, smog potential, global warming potential, acidification potential, and Eutrophication potential are all increased by 1 to 3% when the volume of Concrete 20MPa is increased by 10%. The dependant relationship where Weighted resource use is affected by 4% with a 10% increase in concrete 20MPa means that output is greatly affected by the concrete 20MPa input.

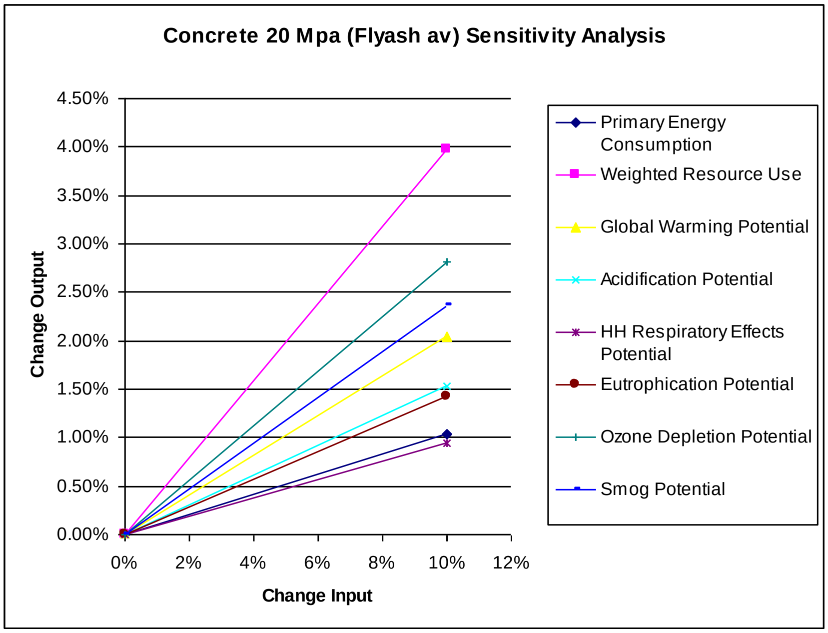

Figure 7: Concrete 20 Mpa (Flyash Av) Sensitivity Analysis

The Rebar, Rod, and Light Sections sensitivity analysis shows that these materials generally only have a significant effect on the Eutrophication potential of the project. With a 10% change in input, the Eutrophication potential is affected by 3%. Other factors are all below 1% with a 10% increase in material use.

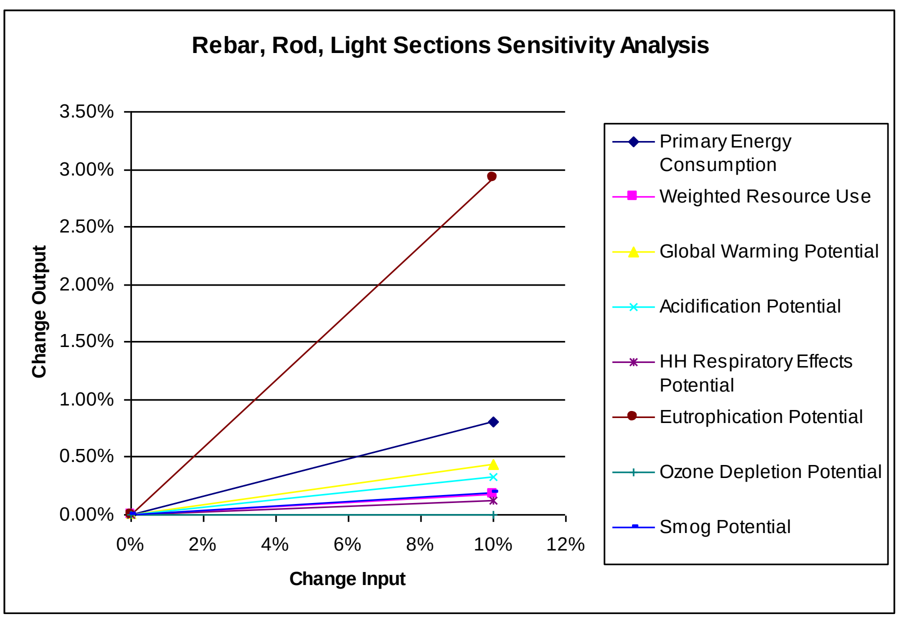

Figure 8: Rebar, Rod, Light Sections Sensitivity Analysis

The Softwood Plywood input has relatively little influence on the overall impact of outputs as seen in the chart above. The most significant affect due to a 10% increase in material use is a 0.25% change in the weighted resource use which is almost insignificant.

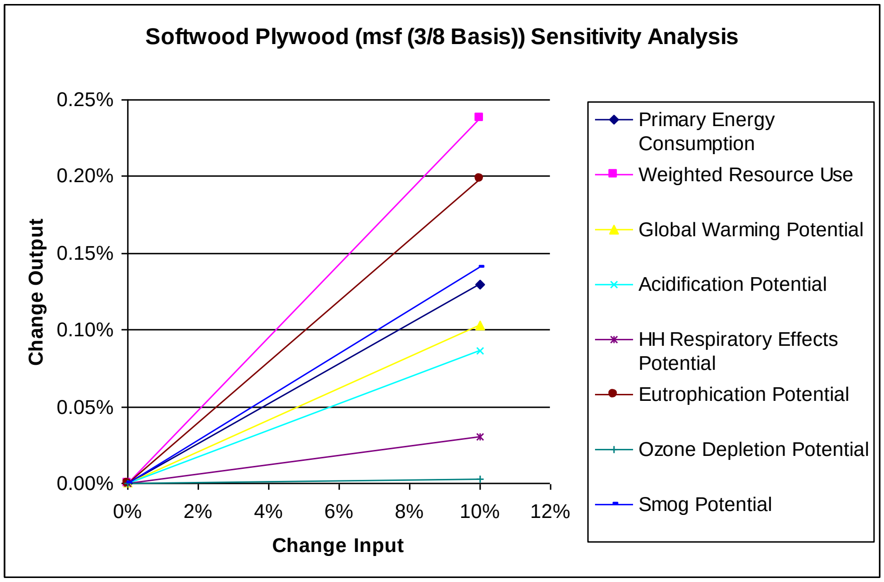

Figure 9: Softwood Plywood Sensitivity Analysis

The Gypsum Board input has relatively little influence on the overall impact of outputs as seen in the chart above. The most significant affect due to a 10% increase in material use is a change of 0.3% in primary energy consumption which is almost insignificant.

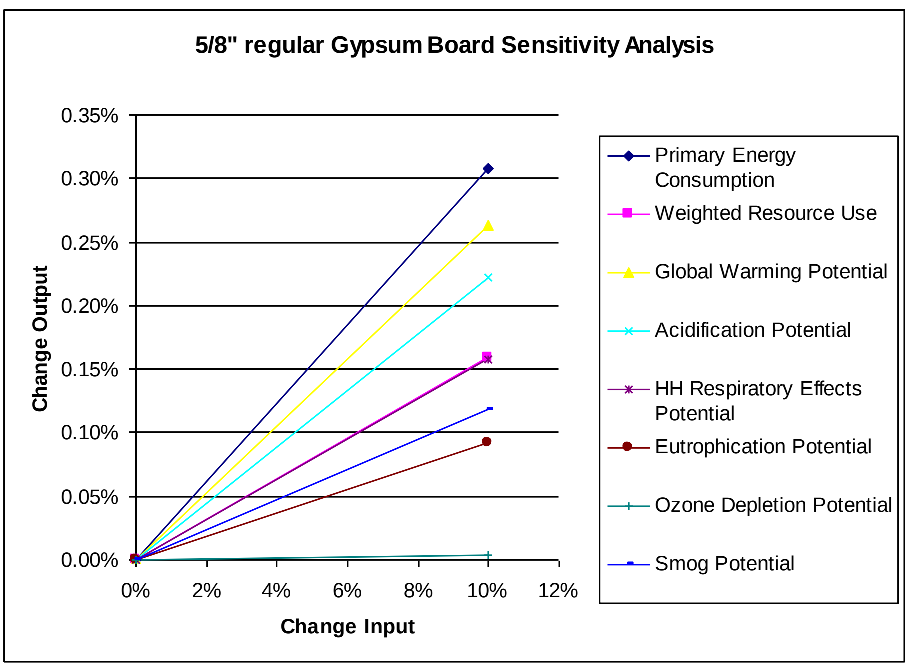

Figure 10: 5/8" Regular Gypsum Board Sensitivity Analysis

4.5 Chain of Custody Inquiry

The Material selected for our sensitivity analysis was fibreglass insulation, which is used throughout our building. After contacting the architectural engineering firm, Raymond Letkeman Architects Inc, and their general contractor, it was discovered that the insulation was provided by JohnsManville.

The product specialist at JohnsManville said that the insulation in our building most likely came from the manufacturing facility which is located in Innisfail Alberta, which is between Edmonton and Calgary. This plant is the only insulation factory in the northwest, and often supplies insulation to Vancouver.

The insulation is transported by both Truck (68.7%) and Railcar (31.3%), and the source material is from sand quarries within 500 miles of their manufacturing facility. The representatives from JohnsManville were hesitant to provide the source of the sand they use, but it is very possible that it came from the Canadian Silica Industries plants which are located throughout northern Alberta, particularly in the north-west and into north-eastern BC.

JohnsManville has also provided a LEED document for their point of origin, which details a few more facts about their product as it relates to environmental impact. This document is in Appendix C.

The information provided by JohnsManville was relatively easy to obtain, but not very detailed. To find out further information required many more phone calls, and it as often mentioned that the information being requested was privileged. Completing this for every material in the Bi building would be time consuming, and would likely lead to many dead ends. Companies seem hesitant to provide anything quickly or without getting input from someone else at their company. This reluctance might change if the method of collection was from a recognizable accredited organization rather than a university student. The companies may then treat the LCA practitioners as professionals rather than people from the general public

4.6 Building Function

The Bi Building is considered a multi-unit residential building. While its main function is to provide shelter, there are many secondary functions. Each of them have been given a functional area, and it is presented below

Functional Area Type	Gross Floor Area (ft2)	Percent of Building
Bedroom	19512	17%
Bathroom	6960	6%
Kitchen	7372	7%
Living Area/Balconies	41248	37%
Hallway/Stairwell/Elevator	9940	9%
Parking	21416	19%
Storage/Mechanical/Operational	6137	5%
Whole Building	112585	100%

Table 13: Summary of Functional Area

A majority of this building consists of Living Area and Balcony, as well as the Bedrooms and Parking. This makes sense as it is a residential building. The basement floor is almost exclusively parking. A majority of the units have at least 2 bedrooms, indicating a large residential population potential. In this building, it is assumed that dens are part of the building living area, as well as area that is not exclusively part of the Kitchen, Bathroom, or Bedrooms within each unit. Closest are considered to be part of their respective functional area.

4.7 Functional Units

Functional units are used as reference units for the quantified impact of a product system. In this case, the product system is the Bi Building. Functional Units have several uses. By providing a reference point, the functional unit makes it easier for the comparison of several different product systems. The Bi building is defined as a low rise residential building. The environmental impact of the building can be compared to other low rise residential buildings with similar properties. There are however key differences such as the gross floor area that make direct comparisons of absolute values pointless. As this is a complicated product system with various functions, four specific functional units are used. The total effects of each impact category on the building are divided by these units, so they can provide a better comparative analysis in the future.

4.7.1Per Typical Residential Building Square Foot constructed

The gross floor area is shown to be 112585, including parking. This value is divided by the Impact Assessment results to provide impact per square feet of the building. This is a common functional unit for many different building types, as shelter is directly correlated to floor space.

	Total Effects	Per Gross Floor Area (/ft^2)
Fossil Fuel Consumption MJ	323039220	2869.291824
Weighted Resource Use kg	17292875.16	153.5983938
Global Warming Potential (kg CO2 eq)	18557165.78	164.828048
Acidification Potential (moles of H+ eq)	7796762.905	69.25223524
HH Respiratory Effects Potential (kg PM2.5 eq)	42190.2069	0.374740924
Eutrophication Potential (kg N eq)	1353.036841	0.012017914
Ozone Depletion Potential (kg CFC-11 eq)	0.002559055	2.273E-08
Smog Potential (kg NOx eq)	15581.06947	0.138393831

Table 14: Functional Unit Summary – Per Gross Floor Area

4.7.2 Per Specific type of function

Apart from providing basic shelter, there are more specific functions within a residential building. Each unit contains at least two bedrooms, two bedrooms, a kitchen, and a living area/balcony. Other function types include corridors, parking, and storage. Each impact category is allocated to the specific unit type and divided by its total area. For example, bedrooms contribute to 17% of the building. This percentage is multiplied by the impact results for each category. The number is then divided by the total area of bedroom in the building.

	Total Effects	Bedroom	Bathroom	Kitchen	Living Area/Balcony	Hallway/ Stairwell/ Elevator	Parking	Storage /Mechanical /Operational	Whole Building
		17%	6%	7%	37%	9%	19%	5%	100%
Fossil Fuel Consumption MJ	323039220	2,814.51	2,784.82	3,067.38	2,897.70	2,924.90	2,865.96	2,631.90	2,869.29
Weighted Resource Use kg	17292875.16	150.67	149.08	164.20	155.12	156.58	153.42	140.89	153.60
Global Warming Potential (kg CO2 eq)	18557165.78	161.68	159.98	176.21	166.46	168.02	164.64	151.19	164.83
Acidification Potential (moles of H+ eq)	7796762.905	67.93	67.21	74.03	69.94	70.59	69.17	63.52	69.25
HH Respiratory Effects Potential (kg PM2.5 eq)	42190.2069	0.37	0.36	0.40	0.38	0.38	0.37	0.34	0.37
Eutrophication Potential (kg N eq)	1353.036841	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ozone Depletion Potential (kg CFC-11 eq)	0.002559055	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smog Potential (kg NOx eq)	15581.06947	0.14	0.13	0.15	0.14	0.14	0.14	0.13	0.14

Table 15: Functional Unit Summary – Per Gross Floor Area

4.7.3 Per Typical Residential Building cubit foot constructed

The total volume of the building is estimated to be 1,118,419.39 ft^3. As the building is large it occupies a greater amount of space. This needs to be taken into account when analyzing the impact of the building. The summary below, shows the impact per cubic feet of building space

	Total Effects	Per building Volume (/ft^3)
Fossil Fuel Consumption MJ	323039220	288.84
Weighted Resource Use kg	17292875.16	15.46
Global Warming Potential (kg CO2 eq)	18557165.78	16.59
Acidification Potential (moles of H+ eq)	7796762.905	6.97
HH Respiratory Effects Potential (kg PM2.5 eq)	42190.2069	0.04
Eutrophication Potential (kg N eq)	1353.036841	0.00
Ozone Depletion Potential (kg CFC-11 eq)	0.002559055	0.00
Smog Potential (kg NOx eq)	15581.06947	0.01

Table 16: Functional Unit Summary – Per Gross Floor Area

4.7.4 Per Residential Building occupant

The current occupancy of the building is not known as of the writing of this result. In addition the occupancy can fluctuate over the life cycle of this building. For this reason, the average occupancy is approximated. This is a conservative estimation. An average occupancy of 320 people is taken. As the building is directly used by people almost exclusively, the impact is divided by the amount of people. It is shown as impact per person. Pets are not taken into account.

	Total Effects	Per Occupancy (/person)
Fossil Fuel Consumption MJ	323039220	1009497.562
Weighted Resource Use kg	17292875.16	54040.23488
Global Warming Potential (kg CO2 eq)	18557165.78	57991.14307
Acidification Potential (moles of H+ eq)	7796762.905	24364.88408
HH Respiratory Effects Potential (kg PM2.5 eq)	42190.2069	131.8443966
Eutrophication Potential (kg N eq)	1353.036841	4.228240128
Ozone Depletion Potential (kg CFC-11 eq)	0.002559055	7.99705E-06
Smog Potential (kg NOx eq)	15581.06947	48.6908421

Table 17: Functional Unit Summary – Per Gross Floor Area

5.0 Fenestration Ratio Analysis

As the UBC community expands, the need for more sustainable building practice has arisen. As part of this report, the fenestration or glazing ratio of the Bi Building is analyzed from a Life Cycle Assessment prospective. To find the base case fenestration ratio for the building, the total window area is divided by the wall envelope area. A Fenestration Ratio (FR) of 31% has been found. Using this value, the annual operating energy is found.

In this section of the report, the change in percentage of each Impact Category is shown for percent change in FR. This value is shown in the form a stacked chart, with each section representing change in respective Impact Category

5.1 Manufacturing

The Manufacturing Phase in a Building Life Cycle represents the creation of individual materials that go into the building. An increase in window area while keeping the wall envelope constant, increases the amount of Glazing, while decreasing other components such as plywood. This however represents an increase in the Impact due to Manufacturing. The largest change is in Impact to Human Health

Respiratory Effects. This may indicate that the manufacturing of Standard Glazing has a greater Human Health effect.

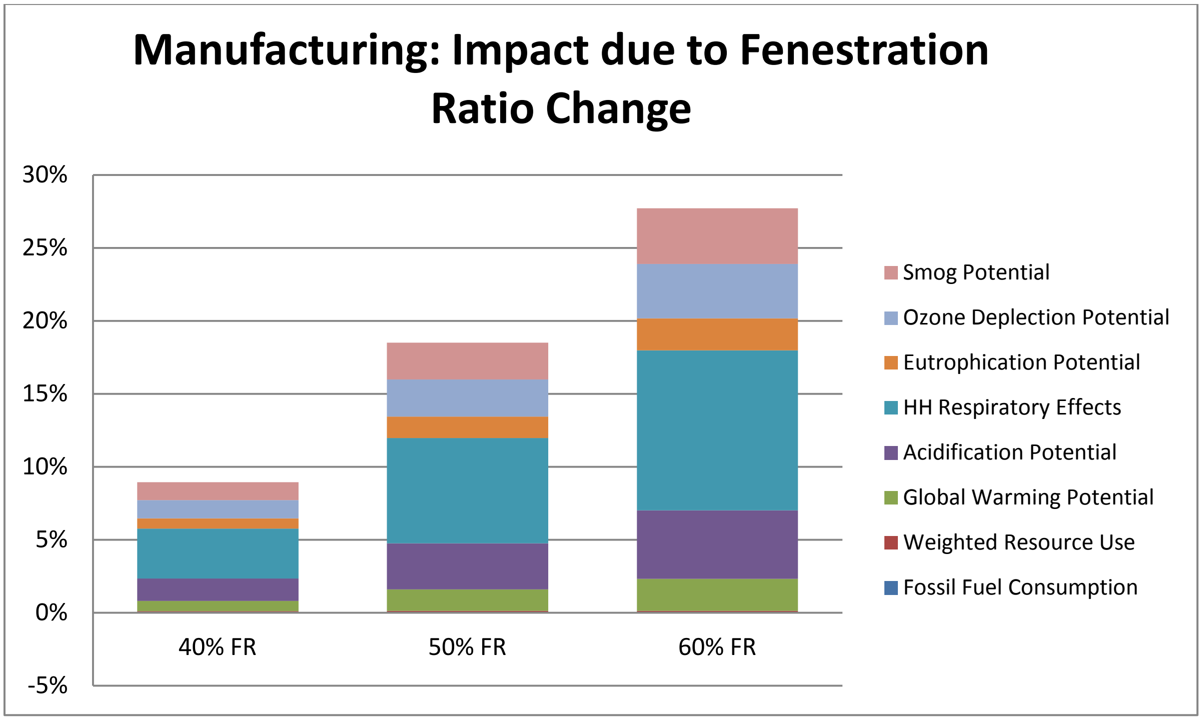

Figure 11: Manufacturing – Impact Change due to Fenestration Ratio Change

5.2 Construction

During construction, there is impact associated with transportation and construction activities. As shown below, as the fenestration ratio increases, so does Impact associated with Construction. As there are larger windows, greater challenges may arise in fitting window sections into the wall envelope. The change however is small, with a less than 6% difference when increasing the ratio from 30% to 60%.

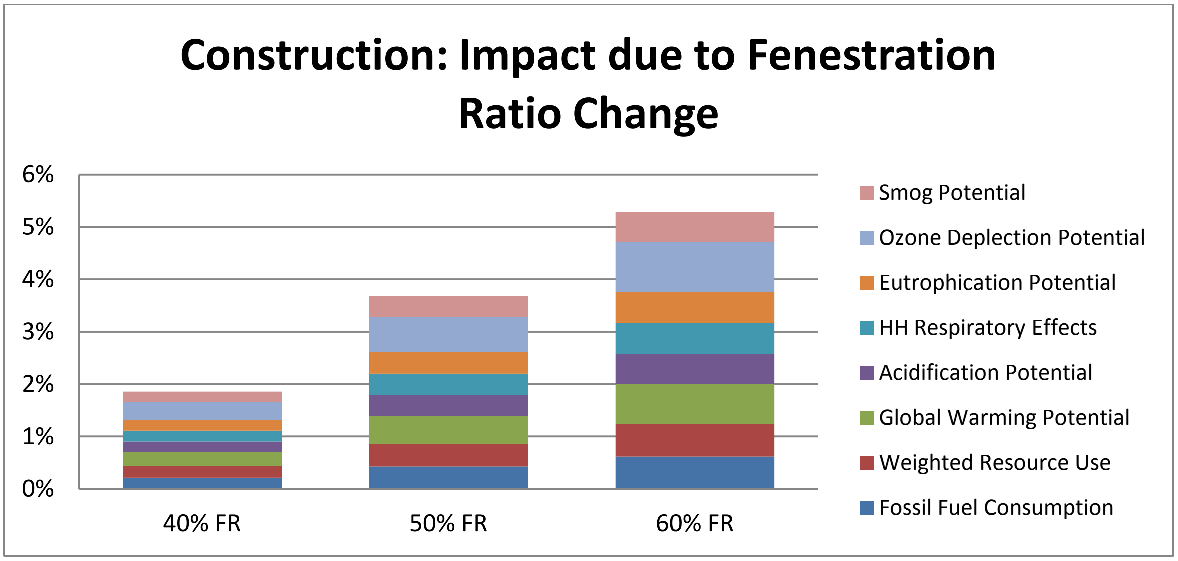

Figure 12: Construction – Impact Change due to Fenestration Ratio Change

5.3 Maintenance

When considering the Maintenance of a building over a period of time, elements of the building need to be repaired, replaced, or generally maintained. There is cost associated with these activities in terms of their environmental impact. When increasing the fenestration ratio, there is more maintenance involved since the number of windows and window size increases. These windows have to be repaired, replaced, or generally cleaned at a higher rate. For this reason, out of the life cycle sections for a building the greatest percent difference associated with an increase in fenestration ratio is found in the Maintenance section.

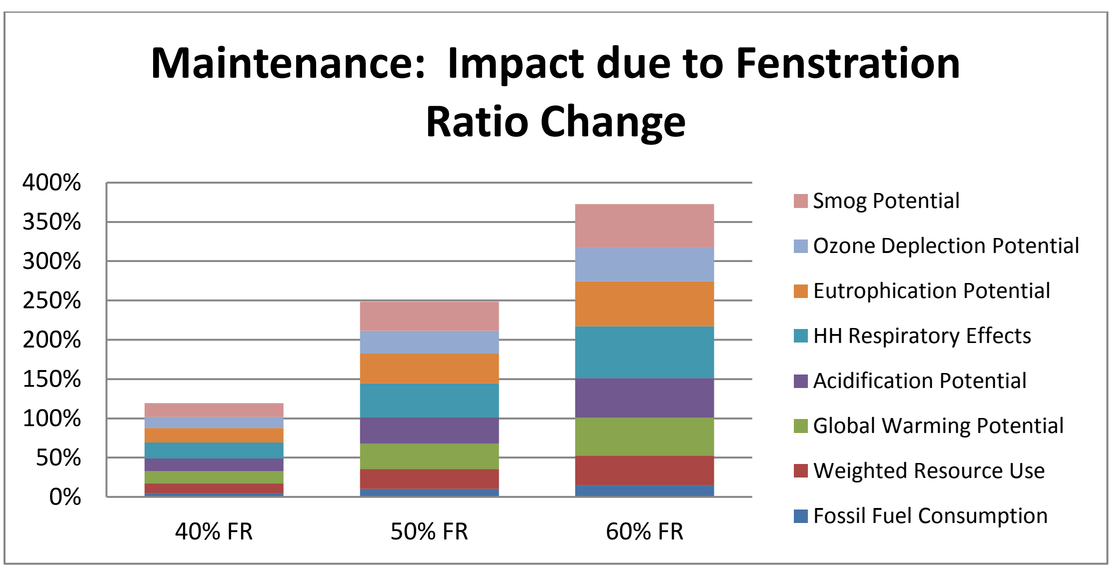

Figure 13: Maintenance – Impact Change due to Fenestration Ratio Change

5.4 End of Life

Under the ATHENA Impact Estimator, the end of life calculation takes into account the environmental cost associated with demolition of a building. It estimates the energy required to demolish the structural systems components (wood, steel, and concrete). Due to an increase in window area, there is less overall wood used in the building. For this reason, the end of life impact in a building with a greater fenestration ratio is less.

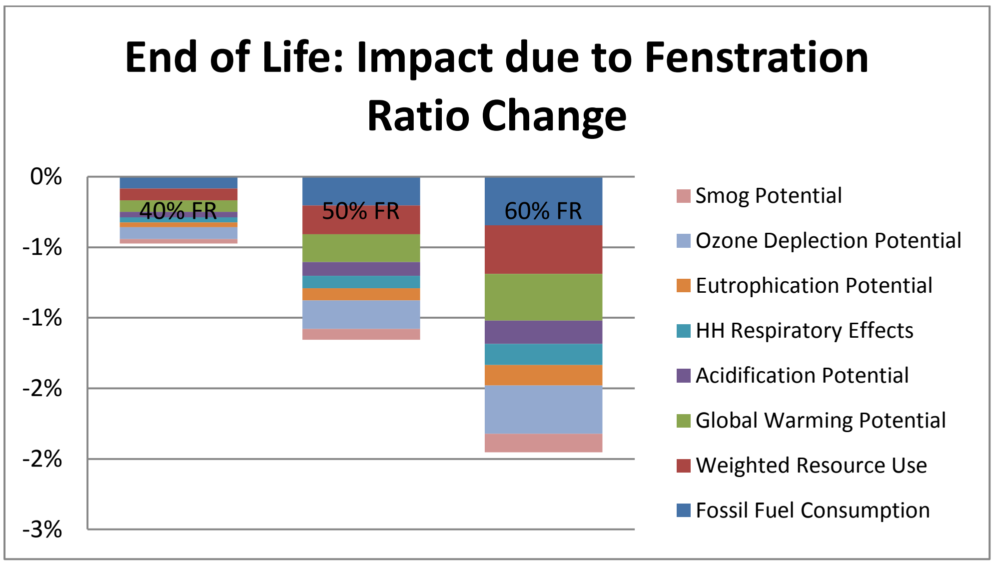

Figure 14: End of Life – Impact Change due to Fenestration Ratio Change

5.5 Operating Energy

When inputting changes in Impact Estimator to analyze Fenestration Ratio change, the total energy use Intensity in terms of Electric and Natural Gas is also inputted. These values have been provided by the instructor of this course. As there is less insulation due to an increase in window area, more energy is required to maintain sufficient temperature and insulation requirements.

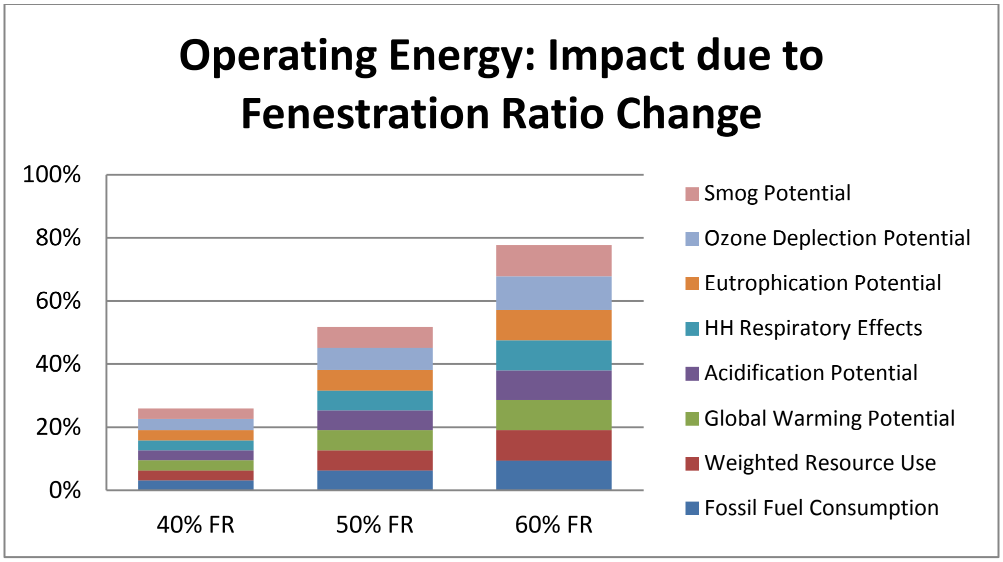

Figure 15: Operating Energy – Impact Change due to Fenestration Ratio Change

5.6 Total Life Cycle

In total, there is an increase in all Impact Categories as the fenestration ratio increases. This is significant change. As shown below, when doubling the FR (from 30% to 60%) there is an overall change of almost double.

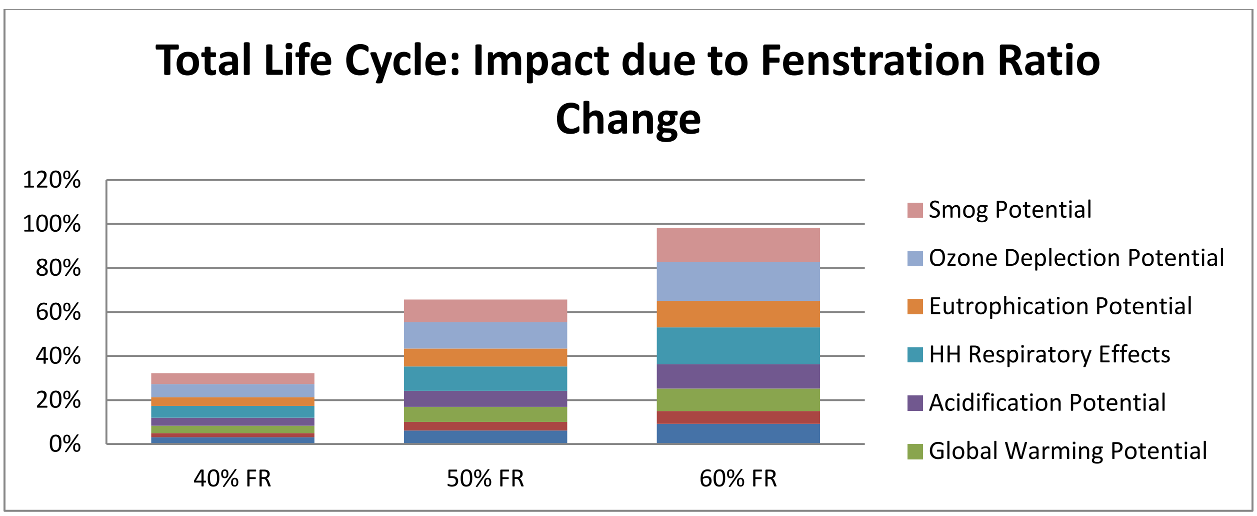

Figure 16: Total Life Cycle – Impact Change due to Fenestration Ratio Change

6.0 Conclusions

The report has been completed as per this study's Goal and Scope. Take-offs of the major building components are inputted into the Athena Institute Impact Estimator and the building model has been generated.

5 major components of the building were chosen to conduct the sensitivity analysis. This included, 20 MPa concrete with average flyash, Rebar, Softwood Plywood, 5/8" Regular Gypsum Board, and Fiberglass Insulation. It has been found that the 20 MPa concrete has the greatest effect on the environmental impact of the building. A 10% increase in concrete results in a 4% increase in weighted resource use, for example.

The fenestration analysis conducted has shown that for the most part, increase in fenestration ratio results in an overall increase of the impact categories within most life cycle stages. Maintenance of the building shows the greatest increase, as glazing has to be repaired or maintained more often than the wall envelope. There is however a decrease in end of life impacts of the building with an increase in Fenestration Ratio. This is due to the fact that less wall components are required, including wood studs. This allows for less general demolition of the building components. There is a relatively small increase in construction due to an increase in window size. Preliminary comparison with other studies however has shown that this is not always the case. Due to less wood framing required there should be a decrease in construction impacts. Due to time constraints more detailed analysis of this difference has not been conducted, and should be revisited at a later date.

In conclusion, to decrease the overall impact of the building, it is recommended that additional building upgrades could be performed during the service life of the building to decrease maintenance impacts. Due to changing technologies, the building could perform better on an environmental level in the future.

7.0 References

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Athena Institute. (2011). The Impact Estimator for Buildings. Retrieved from http://www.athenasmi.org/tools/impactEstimator/

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9.0 Appendix

APPENDIX A: Impact Estimator Inputs

Assembly	Assembly Type	Assembly Name	Input Field	Known/Measured	IE Input
1 Foundation					
	1.1 Concrete Footing				
		1.1.1 Footing_A_26”			
			Length (ft)	228.00	228.00
			Width (ft)	6.00	8.21
			Thickness (in)	26	19
			Concrete (psi)	3625.92	4000
			Concrete flyash %	-	Average
			Rebar	#5	#5
			Category	Insulation	Insulation
			Material	Polylsocyanurate Foam	Polylsocyanurate Foam
			Thickness(in)	3.5	3.5
		1.1.2 Footing_B_26”			
			Length (ft)	7.00	7.00
			Width (ft)	7.00	9.58
			Thickness (in)	26	19
			Concrete (psi)	3625.92	4000
			Concrete flyash %	-	Average
			Rebar	#5	#5
			Category	Insulation	Insulation
			Material	Polylsocyanurate Foam	Polylsocyanurate Foam
			Thickness(in)	3.5	3.5
		1.1.3 Footing_C_36”			
			Length (ft)	10.00	10.00
			Width (ft)	10.00	18.95
			Thickness (in)	36	19
			Concrete (psi)	3625.92	4000
			Concrete flyash %	-	Average
			Rebar	#5	#5
			Category	Insulation	Insulation
			Material	Polylsocyanurate Foam	Polylsocyanurate Foam
			Thickness(in)	3.5	3.5
		1.1.4 Footing_S1_10”			
			Length (ft)	1,807.74	1,807.74

	Width (ft)	2.00	2.00
	Thickness (in)	10	10
	Concrete (psi)	3625.92	4000
	Concrete flyash %	-	Average
	Rebar	#5	#5
	Category	Insulation	Insulation
	Material	Polylsocyanurate Foam	Polylsocyanurate Foam
	Thickness(in)	3.5	3.5
1.1.5 Footing_S2”			
	Length (ft)	160.76	160.76
	Width (ft)	1.33	1.33
	Thickness (in)	10	10
	Concrete (psi)	3625.92	4000
	Concrete flyash %	-	Average
	Rebar	#5	#5
	Category	Insulation	Insulation
	Material	Polylsocyanurate Foam	Polylsocyanurate Foam
	Thickness(in)	3.5	3.5
1.2 Concrete Slab-on-Grade			
1.2.1 SOG_5.5"			
	Length (ft)	50.89	50.89
	Width (ft)	50.89	50.89
	Thickness (in)	5.5	4
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	Average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.2 SOG_6.5"			
	Length (ft)	15.93	15.93
	Width (ft)	15.93	15.93
	Thickness (in)	6.5	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	Average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6	Polyethylene

		mil	6 mil
	Thickness	-	-
1.2.3 SOG_7"			
	Length (ft)	61.69	61.69
	Width (ft)	61.69	61.69
	Thickness (in)	7	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	Average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.4 SOG_8"			
	Length (ft)	98.97	98.97
	Width (ft)	98.97	98.97
	Thickness (in)	8	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	Average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.5 SOG_9"			
	Length (ft)	36.99	36.99
	Width (ft)	36.99	36.99
	Thickness (in)	9	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	Average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.6 SOG_10"			
	Length (ft)	30.47	30.47
	Width (ft)	30.47	30.47
	Thickness (in)	10	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil

	Thickness	-	-
1.2.7 SOG_11"			
	Length (ft)	67.74	67.74
	Width (ft)	67.74	67.74
	Thickness (in)	11	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.8 SOG_12"			
	Length (ft)	41.17	41.17
	Width (ft)	41.17	41.17
	Thickness (in)	12	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.9 SOG_12.5"			
	Length (ft)	23.91	23.91
	Width (ft)	23.91	23.91
	Thickness (in)	12.5	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-
1.2.10 SOG_14.5"			
	Length (ft)	22.08	22.08
	Width (ft)	22.08	22.08
	Thickness (in)	14.5	8
	Concrete (psi)	4351.105	4000
	Concrete flyash %	average	average
	Category	Vapour Barrier	Vapour Barrier
	Material	Polyethylene 6 mil	Polyethylene 6 mil
	Thickness	-	-

2 Walls					
	2.1 Wood Stud				
		External Wall Assembly - **Wood Siding**- Main Floor - 3rd Floor			
			Wall Type	Exterior	Exterior
			Length	3575	3575
			Height	9	9
			Sheathing	Plywood	Plywood
			Stud Thickness	2x6	2x7
			Stud Spacing	16	17
			Stud Type		Klin Dried
			Number of Windows	379	379
			Total Window Area	9720	9720
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	Standard	Standard
			Number of Doors	54	54.000
			Door Type	Exterior Wood Frame with Window	Steel Exterior Door - 50% Glazing
			Category	Siding	Siding
			Material	Bevel Ceder Siding	Wood Bevel Siding
			Thickness		
			Category	Sheathing	Sheathing
			Material	Plywood	Plywood
			Thickness		
			Category	Moisture Barrier	Moisture Barrier
			Material	Tyvek "Homewrap"	Tyvek "Homewrap"
			Thickness		
			Category	Insulation	Insulation
			Material	R-20 BATT	Fiberglass BATT

Thickness	6"	6"
Category	Vapour Barrier	Vapour Barrier
Material	6 Mil Poly	6 Mil Poly
Thickness		
Category	Drywall	Drywall
Material	5/8" TypeX	Gypsum Fire Rated Type X 5/8"
Thickness		

External Wall Assembly - **STONE**- Main Floor - 3rd Floor

Wall Type	Exterior	Exterior
Length	241	241
Height	9	9
Sheathing	Plywood	Plywood
Stud Thickness	2x6	2x7
Stud Spacing	16	17
Stud Type		Klin Dried
Number of Windows	23	23
Total Window Area	612	612
Frame Type	Wood Frame	Wood Frame
Glazing Type	Standard	Standard
Number of Doors	0	-
Door Type	-	-
Category	Siding	Siding
Material	Stone	Natural Stone
Thickness	4"	4"
Category	Sheathing	Sheathing
Material	Plywood	Plywood
Thickness		
Category	Moisture Barrier	
Material	Tyvek "Homewrap"	
Thickness		
Category	Insulation	Insulation
Material	R-20 BATT	Fiberglass BATT
Thickness	6"	6"
Category	Vapour Barrier	Vapour Barrier
Material	6 Mil Poly	6 Mil Poly
Thickness		
Category	Drywall	Drywall

			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Party Wall Assembly: Main Floor - 2nd Floor			
			Wall Type		
			Length	769	769
			Height	9	9
			Sheathing	Exterior Plywood Sheating	Exterior Plywood Sheating
			Stud Thickness	2 - 2 x 4	2 - 2 x 4
			Stud Spacing	16	16
			Stud Type		
			Wall Envelope		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Insulation	Insulation
			Material	Acoustic	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Drywall	Drywall
			Material		Gypsum Regular
			Thickness	1/2"	1/2"
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Party Wall Assembly: 3rd Floor			
			Wall Type		
			Length	391	391
			Height	9	9
			Sheathing	Exterior Plywood Sheating	Exterior Plywood Sheating
			Stud Thickness	2 x 4	2 x 4
			Stud Spacing	16	16
			Stud Type		Klin Dried
			Wall Envelope		
			Category	Drywall	Drywall

			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Insulation	Insulation
			Material	Acoustic	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Drywall	Drywall
			Material		Gypsum Regular
			Thickness	1/2"	1/2"
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Corridor Wall Assembly Main Floor - 3rd Floor			
			Wall Type		
			Length	2104	2104
			Height	9.4	9.4
			Sheathing	None	None
			Stud Thickness	2x4	2x4
			Stud Spacing	16 OC	16 OC
			Stud Type		Klin Dried
			Number of Doors	78	78.000
			Door Type	-	Solid Wood Door
			Category	Drywall	Drywall
			Material		Regular
			Thickness	1/2"	
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic (R-12 Batt)	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Interior Partition Wall (2x4) Main Floor - 3rd Floor			
			Wall Type		

			Length	5552	5,552.00
			Height	9	9.00
			Sheathing	None	None
			Stud Thickness	2-2x4	2 - 2x4
			Stud Spacing	12"	16"
			Stud Type		
			Number of Doors	**522**	522.000
			Door Type	-	Solid Wood Door
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Interior Partition Wall (2x6) Main Floor - 3rd Floor			
			Wall Type		
			Length	1017	1017
			Height	9	9
			Sheathing	None	None
			Stud Thickness	2 - 2x6	2 - 2x6
			Stud Spacing	16	16
			Stud Type		Klin Dried
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		External Wall Assembly - Wood Siding- 4th Floor - 9"			
			Wall Type	Exterior	Exterior
			Length	873	873
			Height	9	9
			Sheathing	Plywood	Plywood
			Stud Thickness	2x6	2x7
			Stud Spacing	16	16
			Stud Type		Klin Dried
			Number of Windows	89	89
			Total Window Area	2592	2592
			Frame Type		Fixed

			Glazing Type		Standard
			Number of Doors	1	1.000
			Door Type	-	Steel Exterior Door - 50% Glazing
			Category	Siding	Siding
			Material	Bevel Ceder Siding	Bevel Ceder Siding
			Thickness		
			Category	Sheathing	Sheathing
			Material	Plywood	Plywood
			Thickness		
			Category	Moisture Barrier	Moisture Barrier
			Material	Tyvek "Homewrap"	Tyvek "Homewrap"
			Thickness		
			Category	Insulation	Insulation
			Material	R-20 BATT	Fiberglass BATT
			Thickness	6"	6"
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		External Wall Assembly - Wood Siding- 4th Floor - 12"			
			Wall Type	Exterior	Exterior
			Length	378	378.00
			Height	12	12.00
			Sheathing	Plywood	Plywood
			Stud Thickness	2x6	2x6
			Stud Spacing	16	16
			Stud Type		Klin Dried
			Number of Windows	53	53
			Total Window Area	1634	1634
			Frame Type		Fixed
			Glazing Type		Standard
			Number of Doors	9	9
			Door Type	-	Steel Exterior Door - 50% Glazing

			Category	Siding	Siding
			Material	Bevel Ceder Siding	Bevel Ceder Siding
			Thickness		
			Category	Sheathing	Sheathing
			Material	Plywood	Plywood
			Thickness		
			Category	Moisture Barrier	Moisture Barrier
			Material	Tyvek "Homewrap"	Tyvek "Homewrap"
			Thickness		
			Category	Insulation	Insulation
			Material	R-20 BATT	Fiberglass BATT
			Thickness	6"	6"
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Party Wall Assembly: 4th Floor			
			Wall Type		
			Length	389	389
			Height	9	9
			Sheathing	Plywood	Plywood
			Stud Thickness	2 x 4	2 x 4
			Stud Spacing	16	16
			Stud Type		Klin Dried
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Insulation	Insulation
			Material	Acoustic	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Drywall	Drywall
			Material		Gypsum Regular

Thickness	1/2"	1/2"
Category	Drywall	Drywall
Material	5/8" TypeX	5/8" TypeX
Thickness		

Party Wall Assembly: 4th Floor (12")

Wall Type		
Length	16	16
Height	12	12
Sheathing	Plywood	Plywood
Stud Thickness	2 x 4	2 x 4
Stud Spacing	16	16
Stud Type		Klin Dried
Category	Drywall	Drywall
Material	5/8" TypeX	5/8" TypeX
Thickness		
Category	Insulation	Insulation
Material	Acoustic	Fiberglass BATT
Thickness	3.5"	3.5"
Category	Insulation	Insulation
Material	Acoustic	Fiberglass BATT
Thickness	3.5"	3.5"
Category	Drywall	Drywall
Material		Gypsum Regular
Thickness	1/2"	1/2"
Category	Drywall	Drywall
Material	5/8" TypeX	5/8" TypeX
Thickness		

Corridor Wall Assembly - 4th Floor

Wall Type		
Length	687	687
Height	9	9
Sheathing	None	None
Stud Thickness	2x4	2x4
Stud Spacing	16 OC	16 OC
Stud Type		Kiln Dried
Number of Doors	26	26.000
Door Type	-	Solid Wood Door

			Category	Drywall	Drywall
			Material		Regular
			Thickness	1/2"	
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic (R-12 Batt)	Fiberglass BATT
			Thickness	3.5"	3.5"
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Interior Partition Wall (2x4) 4th Floor			
			Wall Type		
			Length	1575	1,575.00
			Height	9	9.00
			Sheathing	None	None
			Stud Thickness	2x4	2x4
			Stud Spacing	16	16.00
			Stud Type		Klin Dried
			Number of Doors	161	161.000
			Door Type	-	Solid Wood Door
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" Type X	5/8" Type X
			Thickness		
		Interior Partition Wall (2x4) 4th Floor - 12" Ceiling			
			Wall Type		
			Length	310	310.00
			Height	12	12.00
			Sheathing	None	None
			Stud Thickness	2x4	2x4
			Stud Spacing	16	16.00
			Stud Type		Klin Dried
			Number of Doors	13	13.000
			Door Type	-	Solid Wood Door
			Category	Drywall	Drywall

			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" Type X	5/8" Type X
			Thickness		
		Interior Partition Wall (2x6) 4th Floor			
			Wall Type		
			Length	313	313.00
			Height	9	9.00
			Sheathing	None	None
			Stud Thickness	2x6	2x6
			Stud Spacing	16	16.00
			Stud Type		Klin Dried
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Interior Partition Wall (2x6) 4th Floor- 12" Ceiling			
			Wall Type		
			Length	20	20
			Height	12	12
			Sheathing	None	None
			Stud Thickness	2x6	2x6
			Stud Spacing	16	16
			Stud Type		Klin Dried
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
	Concrete Cast in Place	Exterior Concrete Wall	**Wall Type**	Concrete	Concrete
			Length (ft)	1720	1720
			Height (ft)	9.33	9.33
			Thickness (in)	8"	8"
			Concrete (psi)	3626	4000
			Concrete flyash %	Average	Average
			Rebar		5

			Number of Doors	6	6
			Door Type		Steel Exterior Door
		Interior Concrete Wall	**Wall Type**	Concrete	Concrete
			Length (ft)	171	171
			Height (ft)	9.33	9.33
			Thickness (in)	8"	8"
			Concrete (psi)	3626	4000
			Concrete flyash %		Average
			Rebar		5
			Number of Doors	6	6
			Door Type		Steel Interior Door
	Concrete Block	Elevator Core Wall Assembly Main to Third Floor	**Wall Type**		
			Length (ft)	137	137
			Height (ft)	9	9
			Thickness (in)	8"	7.874
			Rebar	#5	#5
			Category	Insulation	Insulation
			Material	R-12 BATT	Fiberglass BATT
			Thickness		3.5
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Firewall Seperation Assembly (Main to Third Floor)	**Wall Type**		
			Length (ft)	146	146
			Height (ft)	9	9
			Thickness (in)	8"	7.874
			Rebar	#5	#5
			Number of Doors	6	6
			Door Type		Steel Interior Door
			Category	Insulation	Insulation

			Material	Acoustic	Acoustic
			Thickness	3.5"	3.5"
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic	Acoustic
			Thickness	3.5"	3.5"
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Elevator Core Wall Assembly 4th Floor	**Wall Type**		
			Length (ft)	44	44
			Height (ft)	9	9
			Thickness (in)	8"	7.874
			Rebar	#5	#5
			Category	Insulation	Insulation
			Material	R-12 BATT	Fiberglass BATT
			Thickness		3.5
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
		Firewall Seperation Assembly (4th Floor)	**Wall Type**		
			Length (ft)	58	58
			Height (ft)	9	9
			Thickness (in)	8"	7.874
			Rebar	#5	#5

			Number of Doors	2	2
			Door Type		Steel Interior Door
			Category	Insulation	Insulation
			Material	Acoustic	Acoustic
			Thickness	3.5"	3.5"
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
			Category	Insulation	Insulation
			Material	Acoustic	Acoustic
			Thickness	3.5"	3.5"
			Category	Vapour Barrier	Vapour Barrier
			Material	6 Mil Poly	6 Mil Poly
			Thickness		
			Category	Drywall	Drywall
			Material	5/8" TypeX	5/8" TypeX
			Thickness		
	Curtain Wall	Lobby (Curtain Wall)	**Wall Type**		
			Length (ft)	155	155
			Height (ft)	10	10
			Spandral Panel Type	Metal Spandral Panel	Metal Spandral Panel
			Viewable Glazing (%)	-	75
			Spandral Panel (%)	-	25
			Number of Doors	4	4
			Door Type	-	Steel Exterior Door (50% Glazing)
3 Columns and Beams					
	3.1 Columns and Beams				
		3.1.1 Columns and Beams			
			Number of Concrete Columns		

Foundation	39	39
2nd over Main	132	132
3rd over 2nd	120	120
4th over 3rd	116	116
Roof over 4th	111	111
Total	518	518
Number of Wood Columns (posts)		
Foundation	0	0
2nd over Main	440	440
3rd over 2nd	388	388
4th over 3rd	347	347
Roof over 4th	283	283
Total	1458	1458
Number of Beams	None (see assumptions + Extra materials)	
Supported Area Total (m2)		
Foundation	2922.7	2922.7
2nd over Main	2154.1	2154.1
3rd over 2nd	2154.1	2154.1
4th over 3rd	2154.1	2154.1
Roof over 4th	2122.2	2122.2
Total	11507.1	11507.1
Floor Area Supported by Concrete Columns (m2)		
Foundation	2922.7	2922.7
2nd over Main	1174.9	1174.9
3rd over 2nd	1191.2	1191.2
4th over 3rd	1232.4	1232.4
Roof over 4th	1296.1	1296.1
Total	6754.3	6754.3
Floor Area Supported by Wood Columns (m2)		
Foundation	0.0	0.0

2nd over Main	979.1	979.1
3rd over 2nd	962.9	962.9
4th over 3rd	921.6	921.6
Roof over 4th	826.1	826.1
Total	4752.8	4752.8
Supported Area Concrete Columns (m2) (per Column)		
Foundation	74.942	74.942
2nd over Main	8.901	8.901
3rd over 2nd	9.926	9.926
4th over 3rd	10.624	10.624
Roof over 4th	11.676	11.676
Supported Area Wood Columns (m2) (per Column)		
Foundation	0.000	1.000
2nd over Main	2.225	2.225
3rd over 2nd	2.482	2.482
4th over 3rd	2.656	2.656
Roof over 4th	2.919	2.919
Bay Sizes, Supported Span Concrete Columns (m)		
Foundation	7.544, 8.930	7.544, 8.930
2nd over Main	2.983	3.05, 2.9175
3rd over 2nd	3.151	3.151
4th over 3rd	3.259	3.259
Roof over 4th	3.417	3.417
Bay Sizes and Supported Span Wood Columns (m)		
Foundation	0.000	0.000
2nd over Main	1.492	3.05, 0.7299
3rd over 2nd	1.575	3.05, 0.8133
4th over 3rd	1.630	3.05, 0.8711
Roof over 4th	1.709	3.05, 0.9576
Live Load	2.400	2.400

			Concrete Columns (kPa)		
			Live Load Wood Columns (kPa)	2.400	2.400
	Extra Materials				
		Beams			
			Parallel Strand Lumber (m3)	0.2288	0.2288
			Laminated veneer Lumber (m3)	43.2303	43.2303
			Glulam Beams (m3)	0.7174	0.7174
4 Floors					
	4.1 Wood I Joist Floor				
		4.1.1 - Floor_WoodI-joist_Second Floor_West-Entire floor			
			Floor Width (ft)	971.06	971.06
			Span (ft)	13.22	13.22
			Decking Type	Plywood	Plywood
			Live load (psf)	40	50
			Decking Thickness	5/8"	5/8"
			Web Thickness	3/8"	3/8"
			Web Type	OSB	OSB
			Flange Size	2.5" x 1.5"	2.5" x 1.5"
			Flange Type	LVL	LVL
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	3.5	3.5
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"
			Thickness(in)	-	-
		4.1.2 - Floor_WoodI-Joist_Second Floor_East-Entire floor			
			Floor Width (ft)	942.65	942.65
			Span (ft)	10.32	10.32
			Decking Type	Plywood	Plywood
			Live load (psf)	40	50
			Decking Thickness	5/8"	5/8"
			Web Thickness	3/8"	3/8"

			Web Type	OSB	OSB
			Flange Size	2.5" x 1.5"	2.5" x 1.5"
			Flange Type	LVL	LVL
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	3.5	3.5
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"
			Thickness(in)	-	-
		4.1.3 - Floor_WoodI-Joist_Third Floor_West-Entire floor			
			Floor Width (ft)	1,054.82	1,054.82
			Span (ft)	12.06	12.06
			Decking Type	Plywood	Plywood
			Live load (psf)	40	50
			Decking Thickness	5/8"	5/8"
			Web Thickness	3/8"	3/8"
			Web Type	OSB	OSB
			Flange Size	2.5" x 1.5"	2.5" x 1.5"
			Flange Type	LVL	LVL
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	3.5	3.5
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"
			Thickness(in)	-	-
		4.1.4 - Floor_WoodI-Joist_Third Floor_East-Entire floor			
			Floor Width (ft)	914.36	914.36
			Span (ft)	10.63	10.63
			Decking Type	Plywood	Plywood
			Live load (psf)	40	50
			Decking Thickness	5/8"	5/8"
			Web Thickness	3/8"	3/8"
			Web Type	OSB	OSB
			Flange Size	2.5" x 1.5"	2.5" x 1.5"
			Flange Type	LVL	LVL
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt

			Thickness (in)	3.5	3.5
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"
			Thickness(in)	-	-
		4.1.5 - Floor_WoodI-Joist_Fourth Floor_West-Entire floor			
			Floor Width (ft)	1,119.36	1,119.36
			Span (ft)	11.44	11.44
			Decking Type	Plywood	Plywood
			Live load (psf)	40	50
			Decking Thickness	5/8"	5/8"
			Web Thickness	3/8"	3/8"
			Web Type	OSB	OSB
			Flange Size	2.5" x 1.5"	2.5" x 1.5"
			Flange Type	LVL	LVL
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	3.5	3.5
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"
			Thickness(in)	-	-
		4.1.6 - Floor_WoodI-Joist_Fourth Floor_East-Entire floor			
			Floor Width (ft)	896.14	896.14
			Span (ft)	10.86	10.86
			Decking Type	Plywood	Plywood
			Live load (psf)	40	50
			Decking Thickness	5/8"	5/8"
			Web Thickness	3/8"	3/8"
			Web Type	OSB	OSB
			Flange Size	2.5" x 1.5"	2.5" x 1.5"
			Flange Type	LVL	LVL
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	3.5	3.5
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"

			Thickness(in)	-	-
5 Roofs					
	5.1 Light Frame Wood Truss				
		5.1.1 - Roof_LFWT_Main			
		Envelope	Roof Width (ft)	800.79	800.79
			Span (ft)	21.31	21.31
			Live load (psf)	38	50
			Truss Type	Pitched	Pitched
			Decking Type	Plywood	Plywood
			Decking Thickness	5/8"	5/8"
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	7.250	7.250
			Category	Vapour Barrier	Vapour Barrier
			Material	Polytheylene 6 mil	Polytheylene 6 mil
			Thickness (in)	-	-
			Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (in)	7.25"	7.25"
			Category	Asphalt-Fiberglass,Glass Felt	Gypsum board
			Material	7.25"	7.25"
			Thickness (in)	-	-
			Category	Gypsum board	Gypsum board
			Material	Gypsum Fibre BD 5/8"	Gypsum Fibre BD 5/8"
			Thickness (in)	-	-

APPENDIX B: Impact Estimator Input Assumptions

Assembly	Assembly Type	Assembly Name	Modeling Assumptions
1 Foundation	The SOG inputs of the Impact Estimator are limited to two options, 4" & 8". Since the SOG values of the Bi building were different than these two values, the areas measured on the OnScreen takeoff had to be adjusted to make up for these changes. For concrete input of the Impact Estimator a value of 4000 psi has been chosen to be the closest estimate to the actual value.The Impact Estimator limits the thickness of the footings to be between 7.5" and 19.7" thick. For the selected footings that their thickness would exceed the EI's limitation, a value of 19" tickness has been selected and their width has been adjusted to maintain the same volume of footing while accomodating this limitations.		
	1.1 Concrete Footing		
		1.1.1 Footing_A_26”	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(6.0’) x (26”/12)] / (19”/12) = 8.21 feet
		1.1.2 Footing_B_26”	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(7.0’) x (26”/12)] / (19”/12) = 9.58 feet
		1.1.3 Footing_C_36”	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19”/12) = [(10.0’) x (36”/12)] / (19”/12)

			= 18.95 feet
	1.2 Concrete Slab-on-Grade		
		1.2.1 SOG_5.5"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(1883.68 x (5.5”/12))/(4”/12)] = 50.89 feet
		1.2.2 SOG_6.5"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(312.15 x (6.5”/12))/(8”/12)] = 15.93 feet
		1.2.3 SOG_7"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(4348.619 x (7”/12))/(8”/12)] = 61.69 feet
		1.2.5 SOG_9"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet)

			inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(1216.32 x (9”/12))/(9”/12)] = 36.99 feet
		1.2.6 SOG_10"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(742.7098 x (10”/12))/(8”/12)] = 30.47 feet
		1.2.7 SOG_11"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(3336.812 x (11”/12))/(8”/12)] = 67.74 feet
		1.2.8 SOG_12"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(1130/210 x (12”/12))/(8”/12)] = 41.17 feet
		1.2.9 SOG_12.5"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine

			appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(365.973 x (12.5”/12))/(8”/12)] = 23.91 feet
		1.2.10 SOG_14.5"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(269.098 x (14.5”/12))/(8”/12)] = 22.08 feet
2 Walls			
	2.1 Wood Stud		
		2.1.1 Interior Partition Wall (2x4) Main Floor - 3rd Floor	Studs are specified to be 12" OC, however IE input only allows studs to be 16" or 24" OC. It is therefore assumed that the studs are 16" OC.
	2.2 Concrete Cast in Place		
		2.2.1 Exterior/Interior Concrete Wall	
			Concrete walls have a stated psi of 3600 psi. As this is not an available input in Impact Estimator, the strenght is assumed to be 4000 psi
3 Columns and Beams			
	3.1 Conrete Columns	Assume that one column is equivalent to 4 wood posts when calculating the supported area. The concrete columns and wood posts are scattered throughout the floors and don't really follow a pattern in which to determine which is supporting what area. The total area is therefor just weighted as a postion of the entire floor plan, and the bay sizes and supported spans are calculated to be equivalent. (bay size = supported span = sqrt(supported area / #columns).	

		Supported Area, Bay Size, and Supported Span - Columns Wood Foundation	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Wood = Measured Floor Area * Counted Number of Wood Columns / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2922.7m * 0 / (0 + 4 * 39) = 0 Supported Area per Column (Wood) = Floor Area Supported by Wood / Counted Number of Wood Columns = 0 / 0 = 0 Bay Size = Supported Span = sqrt[Supported Area per Column (wood)] = sqrt(0) = 0 Bay Size and Supported Span (Adjusted where Bay Size ≥ 3.05m) Supported Area per Column Concrete = Bay Size * Supported Span
		Supported Area, Bay Size, and Supported Span - Columns Wood 2nd over Main	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Wood = Measured Floor Area * Counted Number of Wood Columns / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2154.1m2 * 440 / (440 + 4 * 132) = 979.1m2 Supported Area per Column (Wood) = Floor Area Supported by Wood / Counted Number of Wood Columns = 979.1m2 / 440 = 2.225m2 Bay Size = Supported Span = sqrt[Supported Area per Column (wood)] = sqrt(2.225m2) = 1.4916m Bay Size and Supported Span (Adjusted where Bay Size ≥ 3.05m) Supported Area per Column Concrete = Bay Size * Supported Span = 2.225m2 / 3.05m = 0.7299m

		Supported Area, Bay Size, and Supported Span - Columns Wood 3rd over 2nd	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Wood = Measured Floor Area * Counted Number of Wood Columns / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2154.1m2 * 388 / (388 + 4 * 120) = 962.9m2 Supported Area per Column (Wood) = Floor Area Supported by Wood / Counted Number of Wood Columns = 962.9m2 / 388 = 2.4817m2 Bay Size = Supported Span = sqrt[Supported Area per Column (wood)] = sqrt(2.4817m2) = 1.57534m Bay Size and Supported Span (Adjusted where Bay Size ≥ 3.05m) Supported Area per Column Concrete = Bay Size * Supported Span = 2.4817m2 / 3.05m = 0.8133m
		Supported Area, Bay Size, and Supported Span - Columns Wood 4th over 3rd	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Wood = Measured Floor Area * Counted Number of Wood Columns / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2154.1m2 * 347 / (347 + 4 * 116) = 921.6m2 Supported Area per Column (Wood) = Floor Area Supported by Wood / Counted Number of Wood Columns = 921.6m2 / 347 = 2.656m2 Bay Size = Supported Span = sqrt[Supported Area per Column (wood)] = sqrt(2.656m2) = 0.1629m Bay Size and Supported Span (Adjusted where Bay Size ≥ 3.05m) Supported Area per Column Concrete = Bay Size * Supported Span = 2.656m2 / 3.05m = 0.8711

		Supported Area, Bay Size, and Supported Span - Columns Wood Roof over 4th	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Wood = Measured Floor Area * Counted Number of Wood Columns / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2122.2m2 * 283 / (283 + 4 * 111) = 826.1m2 Supported Area per Column (Wood) = Floor Area Supported by Wood / Counted Number of Wood Columns = 826.1m2 / 283 = 2.919m2 Bay Size = Supported Span = sqrt[Supported Area per Column (wood)] = sqrt(2.919m2) = 1.708508m Bay Size and Supported Span (Adjusted where Bay Size ≥ 3.05m) Supported Area per Column Concrete = Bay Size * Supported Span = 2.919m2 / 3.05m = 0.9576m
	3.2 Wood Columns		
		Supported Area, Bay Size, and Supported Span - Columns Concrete Foundation	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Concrete Columns = Measured Floor Area * Counted Number of Concrete Columns * 4 / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2922.7m2 * 4 * 39 / (0 + 4 * 39) = 2922.7m2 Supported Area per Column Concrete = Floor Area Supported by Concrete / Counted Number of Concrete Columns = 2922.7m2 / 39 = 74.942m2 Measured Bay Size = 7.544m Measured Supported Span = 8.93m
		Supported Area, Bay Size, and Supported Span - Columns Concrete 2nd over Main	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Concrete Columns = Measured Floor Area * Counted Number of Concrete Columns * 4 / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2154.1m2 * 4 * 132 / (440 + 4 * 132) = 1174.9m2 Supported Area per Column Concrete = Floor Area Supported by Concrete / Counted Number of Concrete Columns = 1174.9m2 / 132 = 8.901m

			Bay Size = Supported Span = sqrt[Supported Area per Column Concrete] = sqrt(8.901m2) = 2.983m Bay Size and Supported Span (Adjusted where Bay Size ≥ 3.05m) Supported Area per Column Concrete = Bay Size * Supported Span = 8.901m2 / 3.05m = 2.9175m
		Supported Area, Bay Size, and Supported Span - Columns Concrete 3rd over 2nd	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Concrete Columns = Measured Floor Area * Counted Number of Concrete Columns * 4 / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2154.1m2 * 4 * 120 / (388 + 4 * 120) = 1191.2m2 Supported Area per Column Concrete = Floor Area Supported by Concrete / Counted Number of Concrete Columns = 1191.2m2 / 120 = 9.926m Bay Size = Supported Span = sqrt[Supported Area per Column Concrete] = sqrt(9.926m2) = 3.151m
		Supported Area, Bay Size, and Supported Span - Columns Concrete 4th over 3rd	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Concrete Columns = Measured Floor Area * Counted Number of Concrete Columns * 4 / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2154.1m2 * 4 * 116 / (347 + 4 * 116) = 1232.4m2 Supported Area per Column Concrete = Floor Area Supported by Concrete / Counted Number of Concrete Columns = 1232.4m2 / 116 = 10.624m Bay Size = Supported Span = sqrt[Supported Area per Column Concrete] = sqrt(10.624m2) = 3.259m

		Supported Area, Bay Size, and Supported Span - Columns Concrete Roof over 4th	Because of the variability of Supported Area, bay sizes, and span sizes, the following calculations were used; Floor Area Supported by Concrete Columns = Measured Floor Area * Counted Number of Concrete Columns * 4 / (Counted Number of Wood Columns + 4 * Counted Number of Concrete Columns) = 2122.2m2 * 4 * 111 / (347 + 4 * 111) = 1296.1m2 Supported Area per Column Concrete = Floor Area Supported by Concrete / Counted Number of Concrete Columns = 1296.1m2 / 111 = 11.676m Bay Size = Supported Span = sqrt[Supported Area per Column Concrete] = sqrt(11.676m2) = 3.417
	3.3 Wood Columns (posts)		The posts come in many different sizes, and the Impact estimator is unable to account for the differentces. Some wood psots are 4 or 5 studs, while others are 6"x6" or 8"x8". Posts which are not labelled are said to be dependent on the size of the beam they are supporting. All of the posts are generalized to be equivalent in their ability to support load.
	3.4 Extra Materials		
		3.4.1 Laminated Veneer Lumber (LVL)	There are not any beams present in the drawings (or at least they do not follow a pattern which is recognized by the impact estimator) so they are accounted for as extra materials. The LVL beams are generally 2 - 1 3/4" x 9 1/2", but in some cases they are noted as 2 - 1 3/4" x 9 1/4". The assumption is that these two types of beams (which only vary by 1/4 inch in one direction) are the same, and they they are treated as such (2 - 1 3/4" x 9 1/2"). = measured LVL length (ft) * dimensions of LVL (ft^2) *0.028316847 ft^3/m^3 = 43.23025366 m^3
		3.4.2 Fascia Beams	a generalization had to be made by saying that all the beams were 2"x10" because there are only a very limited number of 2"x12" beams in comparison. Another area for uncertainty is that some beams are 3 - 2"x10" compared to the frequent 2 - 2"x10". This is accoutned for by adding an extra linear count of the beams by only measuring to the half way point of each beam.

4 Floors			
	4.1 Wood I Joist Floor		
		4.1.1 - Floor_WoodI-joist_Second Floor_West-Entire floor	The floor width has been calculated using the following equation; ((Residential area* Average residential span)+(Hallway area* Average hallway span))/ (Total area)= Weighted average supported span; ((Total area)/(Supported span))=Width; =((11291.34*14.29343)+(1571.53*5.35958))/(12841.35))= 13.22406332 ft =(12841.35)/(13.224)= 971.06
		4.1.2 - Floor_WoodI-Joist_Second Floor_East-Entire floor	The floor width has been calculated using the following equation; ((Residential area* Average residential span)+(Hallway area* Average hallway span))/ (Total area)= Weighted average supported span; ((Total area)/(Supported span))=Width; =((8858.698*10.75978)+(850.3489*6.029659))/(9730.575))= 10.32261 ft =(9730.575)/(10.32261)= 942.6467754
		4.1.3 - Floor_WoodI-Joist_Third Floor_West-Entire floor	The floor width has been calculated using the following equation; ((Residential area* Average residential span)+(Hallway area* Average hallway span))/ (Total area)= Weighted average supported span; ((Total area)/(Supported span))=Width; =((11140.65*12.77259)+(1646.878*6.780249))/(12722.94))= 12.06176794 ft =(12722.94)/(12.06176794)= 1054.815693
		4.1.4 - Floor_WoodI-Joist_Third Floor_East-Entire floor	The floor width has been calculated using the following equation; ((Residential area* Average residential span)+(Hallway area* Average hallway span))/ (Total area)= Weighted average supported span; ((Total area)/(Supported span))=Width; =((8847.934*11.10419)+(828.8211*6.121654))/(30.04996))= 10.63013721 ft =(30.04996)/(10.63013721)= 914.3636547
		4.1.5 - Floor_WoodI-Joist_Fourth Floor_West-Entire floor	The floor width has been calculated using the following equation; ((Residential area* Average residential span)+(Hallway area* Average hallway span))/ (Total area)= Weighted average supported span; ((Total area)/(Supported span))=Width; =((11162.18*12.09068)+(1496.184*7.765059))/(12809.05))= 11.4431772 ft =(12809.05)/(11.4431772)=

			1119.361622
		4.1.6 - Floor_WoodI-Joist_Fourth Floor_East-Entire floor	The floor width has been calculated using the following equation; ((Residential area* Average residential span)+(Hallway area* Average hallway span))/ (Total area)= Weighted average supported span; ((Total area)/(Supported span))=Width; =((8912.518*11.28513)+(85.3489*5.972364))/(9730.575))= 10.85829946 ft =(9730.575)/(10.85829946)= 896.141707
5 Roofs			
	5.1 Light Frame Wood Truss		
		5.1.1 - Roof_LFWT_Main	The Roof width has been calculated using the following equation; ((Total area)/(Supported span))=Width; =(17060.8)/(21.30502)= 800.787714 ft

APPENDIX C: Chain of Custody Document

Johns Manville

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March 27, 2012

Subject: Green Building Aspects of Johns Manville's Formaldehyde-free™ Building Insulation

To Whom It May Concern:

I have been asked to provide information regarding the point of origin for raw materials, manufacturing and recycled content of Johns Manville's fiber glass building insulation, to which I can provide the following information. Johns Manville's Formaldehyde-free fiber glass insulation is composed of 85 to 98% fiber glass wool and 2 to 15% acrylic thermo-set resin. These materials are processed into fiber glass batts at plants located throughout the United States and Canada. Materials supplied to the market of British Columbia are manufactured at our facility located in Innisfail, Alberta.

Johns Manville's Formaldehyde-free fiber glass batt insulation does not contain volatile organic compounds (VOC's) and has been tested for VOC emissions in accordance with ASTM D 5116 "Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products." The results show that VOC's are not present in excess of ambient or background level concentrations.

Johns Manville's fiber glass building insulation displays the Environmental Choice EcoLogo reserved only for light-density building insulation made with Formaldehyde-free binders and containing at least 45% recycled content. Johns Manville fiber glass building insulation manufactured at the facility located in Innisfail, Alberta features post consumer recycled content in excess of 50%. Locally extracted materials used in the manufacture of the fiber glass insulation supplied to the Innisfail plant account for 68.7% of the finished; within 500 miles. 68.7% of the extracted materials are shipped by truck with the remaining 31.3% shipped via railcar.

If you have any further questions regarding this matter, please feel free to contact me at 303-978-5280.

Sincerely,

Eric Olson
Sr. Technical Product Specialist
Insulation Systems

This proceeding information was offered for your guidance and assistance with the understanding that the comments do not constitute any representations, endorsements of, or an assumption by Johns Manville of any liability for the adequacy of the design of the building, performance of the material and/or the building envelope as a whole either in the context of LEED certification or otherwise as indicated. The proceeding information is not a substitute for review by an architect, engineer, or LEED-related associate/professional. You should consult with the proper professional for any questions regarding all engineering and/or LEED related issues. By accepting this document, you have agreed to the aforementioned disclaimer.