2009

Life Cycle Analysis

UBC's Forest Science Centre

A Life Cycle Analysis of the Forest Sciences Centre located at the University of British Columbia in Vancouver, BC, Canada.

Michael Morris
University of British Columbia
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Michael Morris

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Department of Civil Engineering

Faculty of Applied Science

University of British Columbia

Vancouver, British Columbia, Canada

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Abstract

The Forest Science Centre is an institutional building on the UBC Vancouver campus. The table below shows some of the building envelope characteristics of the FSC.

Table 1: Building summaries

Building system	Specific characteristics of FSC
Structure	Concrete columns throughout
Floors	Basement concrete slab on grade, first, second, third, forth, and fifth floor cast-in place concrete
Exterior Walls	Concrete brick*
Interior Walls	2 x 4 wood studs. Gypsum board on both sides, 1/2"*
Windows	Alumina framed, double glazed, argon filled
Roof	Flat roof, concrete, steel, skylight
Flooring	Carpet on concrete
HVAC/Heating	Steam from central power plant

In viewing the Bill of Materials (BoM), some of the largest groups were chosen to examine in further detail. Water based latex paint, softwood plywood, fiberglass batt, glazing panel, and concrete were found to have significant amounts throughout the FSC. From the BoM, the summary measures were calculated. It was found that the primary energy consumption was 1,556,919,700 MJ, the weighted resource use was 1,301,434,105 kg, the global warming potential was 118,923,477 kg CO_2 eq/kg, and the ozone depletion potential was 0.19 kg CFC-11 eq/kg. If the amount of softwood plywood was increased by 10%, the overall ozone depletion potential of the construction of the FSC increased by 217%. This was by far the most noticeable change in summary measures when increasing a material by 10%.

The energy payback period for improvements using the minimum Residential Environmental Assessment Program's (REAP) R-values was calculated to be just over one year. It is clear that upgrading the building envelopes would be beneficial.

1. Introduction

Figure 1: The main entrance to the Forest Sciences Centre. Source: UBC Faculty of Forestry

The Forest Sciences Centre (FSC) is one of the newest buildings to be constructed at the University of British Columbia, and houses the faculty of Forestry. It is next door to the Center for Advanced Wood Processing building. For the life cycle analysis (LCA) carried out in this report, phase two, which includes the Advance Wood Processing Laboratory building, was excluded. The idea of the FSC was originally conceived in 1988. However, initial challenges and problems with the location of the original design caused the project to be delayed until it was finally completed in 1998 at a cost of $47 million. It currently stands at the end of Main Mall Road on the UBC campus (UBC Library).

Figure 2: The L-shaped atrium that is a main attraction of the FSC. Source: flickr.com

The Forest Sciences Centre is more than 17,000 m^2 (180,000 ft^2 for those still using the British system), has 11 classrooms, 2 lecture theaters, one with a capacity for 250 people, teaching laboratories, multiple computer laboratories, study areas, and a Tim Horton's. In addition to holding the Faculty of Forestry's three departments (Forest Resource Management, Forest Sciences, and Wood Science), the FSC is also home to the Centre for Applied Conservation Research, and the Forest Economics & Policy Analysis Research Unit. The FSC is probably best known for its large, open L-shape atrium (see Figure 2) spanning from the ground floor to the roof of the FSC. The massive columns seen in Figure 2 are Parallam tree columns. The FSC was designed to show off and highlight non-residential Canadian forestry products, using extensive wood finishing throughout the interior of the building. (UBC Faculty of Forestry).

Figure 3: An example of the interior wood finishing throughout the FSC. Source: flickr.com

Currently the Facility of Forestry accommodates approximately 450 undergraduate students and 200 graduate students. The FSC is also used by students in other facilities such as the Facility of Applied Science due to its large lecture theaters. In total, the FSC is four stories high and has a basement with underground walkway. The FSC is a beautifully crafted building showcasing wonderful examples of Parallam beams and hard wood finishing.

The following table summarizes the building structural and envelope characteristics:

Table 2: Building characteristics

Building system	Specific characteristics of FSC
Structure	Concrete columns throughout
Floors	Basement concrete slab on grade, first, second, third, forth, and fifth floor cast-in place concrete suspended slab
Exterior Walls	Cast in place concrete with Fiberglass Batt. insulation and brick cladding
Interior Walls	2 x 4 wood studs. Gypsum board on both sides, 1/2",
Windows	Aluminum framed, double glazed
Roof	Flat roof, suspended slab concrete roof, steel beam support, skylight
HVAC/Heating	Steam from central power plant

2. Goal & Scope

2.1. Goal of Study

This life cycle analysis (LCA) of the Forest Sciences Center (FSC) at the University of British Columbia was carried out as an exploratory study to determine the environmental impact of its design. This LCA of the FSC is also part of a series of twelve others being carried out simultaneously on respective buildings at UBC with the same goal and scope.

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the FSC. An exemplary application of these references is in the assessment of potential future performance upgrades to the structure and envelope of the FSC. When this study is considered in conjunction with the twelve other UBC building LCA studies, further applications include the possibility of carrying out environmental performance comparisons across UBC buildings over time and between different materials, structural types and building functions. Furthermore, as demonstrated through these potential applications, this FSC LCA can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future UBC construction, renovation and demolition projects.

The intended core audience of this LCA study is those involved in building development related policy making at UBC, such as the Sustainability Office, who are involved in creating policies and frameworks for sustainable development on campus. Other potential audiences include developers, architects, engineers and building owners involved in design planning, as well as external organizations such as governments, private industry and other universities whom may want to learn more or become engaged in performing similar LCA studies within their organizations.

2.2. Scope of Study

The product system being studied in this LCA are the structure, envelope and operational energy usage associated with space conditioning of the FSC on a square foot finished floor area of academic building basis. In order to focus on design related impacts, this LCA encompasses a cradle-to-gate scope that includes the raw material extraction, manufacturing of construction materials and construction of the structure and envelope of the FSC, as well as associated transportation effects throughout.

2.3. Tools, Methodology and Data

Two main software tools are to be utilized to complete this LCA study; OnCenter's OnScreen Takeoffs and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings. The study will first undertake the initial stage of a materials quantity takeoff, which involves performing linear, area and count measurements of the building's structure and envelope. To accomplish this, OnScreen TakeOff version 3.6.2.25 is used, which is a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. Using imported digital plans, the program simplifies the calculation and measurement of the takeoff process, while reducing the error associated with these two activities. The measurements generated are formatted into the inputs required for the IE building LCA software to complete the takeoff process. These formatted inputs as well as their associated assumptions can be viewed in Annexes A and B respectively.

Using the formatted takeoff data, version 4.0.51 of the IE software, the only available software capable of meeting the requirements of this study, is used to generate a whole building LCA model for the FSC in the Vancouver region as an Institutional building type. The IE software is designed to aid the building community in making more environmentally conscious material and design choices. The tool achieves this by applying a set of algorithms to the inputted takeoff data in order to complete the takeoff process and generate a Bill of Materials (BoM). This BoM then utilizes the Athena Life Cycle Inventory (LCI) Database, version 4.6, in order to generate a cradle-to-grave LCI profile for the building. In this study, LCI profile results focus on the manufacturing and transportation of materials and their installation in to the initial structure and envelope assemblies. As this study is a cradle-to-gate assessment, the expected service life of the FSC is set to 1 year, which results in the maintenance, operating energy and end-of-life stages of the building's life cycle being left outside the scope of assessment.

The IE then filters the LCA results through a set of characterization measures based on the mid-point impact assessment methodology developed by the US Environmental Protection Agency (US EPA), the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2. In order to generate a complete environmental impact profile for the FSC, all of the available TRACI impact assessment categories available in the IE are included in this study, and are listed as;

- Global warming potential
- Acidification potential
- Eutrophication potential
- Ozone depletion potential
- Photochemical smog potential
- Human health respiratory effects potential
- Weighted raw resource use
- Primary energy consumption

Using the summary measure results, a sensitivity analysis is then conducted in order to reveal the effect of material changes on the impact profile of the FSC. Finally, using the UBC Residential Environmental Assessment Program (REAP) as a guide, this study then estimates the embodied energy involved in upgrading the insulation and window R-values to REAP standards and calculates the energy payback period of investing in a better performing envelope.

The primary sources of data for this LCA are the original architectural and structural drawings from when the FSC was initially constructed in 1998. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as the associated envelope and openings (ie. doors and windows) within each of these assemblies. The decision to omit other building components, such as flooring, electrical aspects, HVAC system, finishing and detailing, etc., are associated with the limitations of available data and the IE software, as well as to minimize the uncertainty of the model. In the analysis of these assemblies, some of the drawings lack sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in the IE software. Furthermore, there are inherent assumptions made by the IE software in order to generate the BoM and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further as they energy in the Building Model section and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Annex B.

3. Building Model

3.1.Takeoffs

Takeoffs were general fairly straight forward. Walls were lineally measured for distance, footings were counted, and exterior walls and windows were found calculating areas. Plan views were used to calculate most items within the building. Profile views were used to determine the height of the columns, the area of the exterior walls and windows, and any exterior metal cladding. As the FSC is a fairly recent building, the drawings were good, and for the most part clean and easy to read. Not all the cross-sections were provided, but it was still fairly easy to determine heights of walls and floor layouts.

There were some challenges encountered during the takeoffs for the FSC. There were four lecture halls that were not on one specific floor, and required some estimation as they were on a steep slope. Not all the data was available for the building, requiring some estimation of materials. Assumptions had to be made regarding what the insulation was and how thick it was.

The interior walls, for the most part, were assumed to be wood stud walls. Some of the heights of the columns in the basement were averaged because of their non-uniformity. The columns were not all the same height, and average heights were required. The beam structure in the building was not well laid out, and therefore assumptions as to the height and span were also made. The IE bases column and beam takeoffs from bay and span sizes as well as live load and the materials the columns and beams are made out of. This data entry made for an easier time modeling the column/beam layout. While assumptions were necessary, it is important to understand that the results of the study give a good estimation of impacts of constructing the building.

3.2.Assembly Groups

The FSC was divided into six assembly groups: foundation, walls, mixed columns & beams, floors, roofs, and extra base materials. Below is a brief outline of each assembly group and some of the uncertainties/problems, and assumptions made when calculating them.

3.2.1. Foundation

The foundation was broken down into a concrete slab on grade, footings, strip footings, and slab on grade concrete pads. The concrete footings and strip footings were named the same as the architectural drawings (i.e. F1, F2…). Any concrete footings not listed in the structural legend were named CF1, CF2, and so on, while any strip footings not listed were named SF1, SF2, and so on. The footings were calculated using the count feature in OnScreen, and the length of the footing was then multiplied by the amount of footings of each type. The IE restricted the height of the footings. If a footing was larger than the allowed height, it was divided by two while the length was multiplied by two. Rebar presented a problem if the reinforcing was greater than 20M bars. The IE only allowed for 10M, 15M, and 20M bars in the footings. Therefore, anything larger than 20M was considered 20M while anything smaller than 10M was considered 10M.

The slab on grade was a simple area calculation. The IE only allowed for two thicknesses, and the area was adjusted accordingly to account for this. The concrete pads were not slabs. They were similar to the concrete footings. However, they were only 100mm thick. They were named

CP1, CP2, and so on. The concrete was assumed to be 20MPa as no information was given. Fly ash was assumed to be “average”, which is an option when entering concrete data in the IE.

3.2.2. Walls

Walls were either concrete block, wood, or concrete brick. However, each wall was labeled W followed by the number in which it was entered (i.e. the first wall was called W1). They were linear measurements, with the height measured from the profile drawings. Floors two through four were the same height, and so walls continuing through these three floors were considered one wall with a height three times the single floor height. Openings included windows and doors. All interior walls were assumed to have no window. Exterior walls were measured by using one meter strips. OnScreen will measure the length of wall accounted for while using a line thickness equal to one meter. For example a 10 meter high wall 5 meters long would have a wall area of 50 meters squared. On OnScreen, 10 one meter strips 5 meters long would be measured. This was done to account for the large windows present throughout the exterior wall.

Area conditions were utilized to calculate the percent glazing area for the curtain walls, as well as the areas of the window openings. Windows were not counted directly, but instead the area of openings for windows was determined using the area function, and then divided by an average exterior window size. These assumptions were made so that a reasonable estimate could be made within the timeframe given. Some other assumptions and calculations were made in order to complete modeling of the walls for the FSC building, such as affecting the length of the concrete cast-in-place walls to accommodate the wall thickness limitation in the IE, and the assumption that interior steel stud walls were light gauge (25Ga) and exterior steel stud walls were heavy gauge (20Ga).

3.2.3. Mixed Columns & Beams

All columns were named C followed by the number in which they were entered (i.e. the first column is C1). The method used to measure column sizing was completely depended upon the metrics built into the IE. That is, the IE calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. A grid system of columns had to be assumed to simplify modeling. An area that appeared to have a slight order to the column distribution was squared off and averaged for span between columns. For example, the foundation columns were broken into three areas. The main atrium in the FSC is an L-shape. The eight columns in the atrium were assumed to be one long line of columns with the spacing between them averaged as the span and the distance to the surrounding walls averaged as the bay size.

3.2.4. Floors

Floors included the roof and were labeled FL# for floors and R# for the roof. There were five floors and one roof for the FSC. However, the roof was broken into three parts to accommodate the three different materials use. The building envelope data was not available for the floors, and therefore average industry standards were assumed. Stairs were assumed to be steel and an area was determined from OnScreen. The average height of the stairs was then multiplied by the area giving a volume. Using online resources, the unit weight of rolled steel was used (7850 kg/m^3) and was added to extra base materials. The values given though are fairly accurate since the steel stairs are not a significant part of the FSC.

The floors were measured using area conditions. Much like in column and beams, the IE calculated the thickness of the material based on some basic variables regarding the assembly. These include; floor width, span, concrete strength, concrete flyash content and live load. Another assumption that had to be made in this assembly group was setting the concrete strength to 20 MPa, instead of the specified 25 MPa. This was due to the IE's limitation to model only 20 MPa, 30 MPa or 60 MPa concrete strengths. Spans were also limited to no more than 10 meters. If a span was greater than 10 meters, the total area was then divided by 10 meters to determine the resulting length.

3.2.5. Roof

The roof was modeled using area conditions. The roof of the FSC was split into three catagories, a suspended slab for the main roof, an open web steel joist system, and glazing for the large skylight. Once again the concrete strength was set to 20 MPa instead of the specified 25 MPa.

Other than these there were no significant assumptions required to complete the takeoffs for the roof assemblies.

3.2.6. Extra Base Material

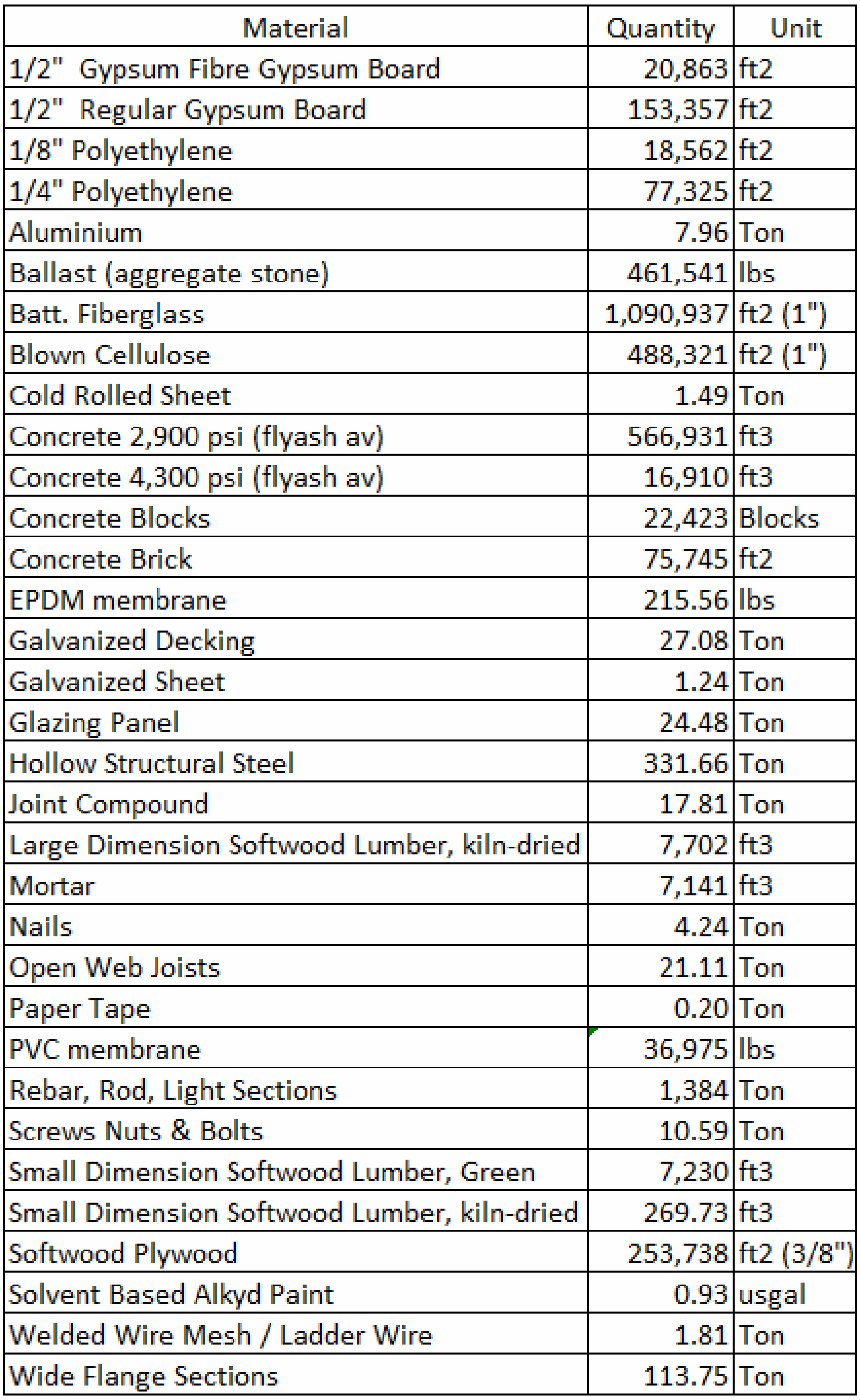
The large Parallam columns within the FSC are not supporting any significant load. The only loads that they are supporting are the additional beams. Their main purpose is aesthetics only. When entering the Parallam column grid into the EIE, the loads that the columns are calculated to take would be greatly exaggerated. Since the Parallam columns are not used for structural support, they were added to extra base material. The length calculator in OnScreen was used and the columns were then multiplied by their average thickness. To account for uncertainty, an additional 5% was added.

The steel staircases were also difficult to model in the IE, and therefore (as explained in floors), the area count was used in OnScreen to determine the total surface area of steel staircases throughout the FSC. Using the architectural drawings, the average height of the steel staircases was then determined and multiplied by the surface area. The unit weight of rolled steel was used (7850 kg/m^3) to determine the total weight of additional steel within the FSC.

3.3.Bill of Materials

Below is the Bill of Materials report produced by the IE version 4.0.51 for the FSC. The five largest amounts of materials in terms of the assembles to the amounts shown below are PVC membrane (36,975 lbs), softwood plywood (253,738 ft^2), fiberglass batt (1,090,937 ft^2), glazing panel (24.48 tons), and 2,900 psi concrete (566,931 ft^3).The concrete was the most significant contributor of the five materials (as seen in the summary measures section).

Table 3: A table showing the Bill of Materials produced by Athena for the FSC.

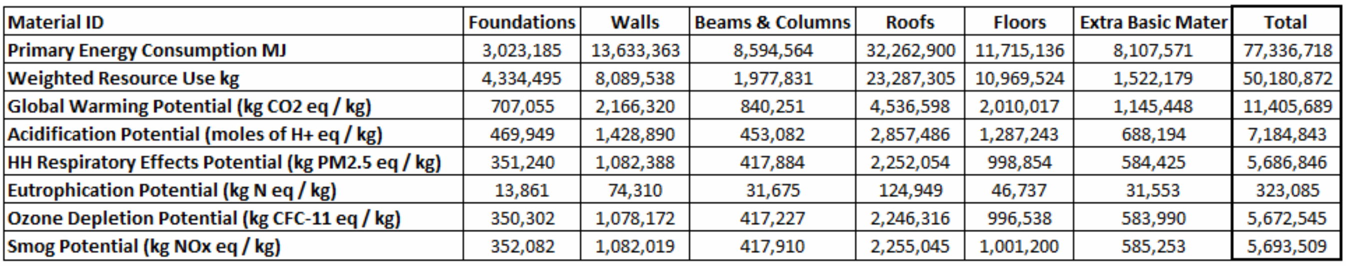


Material	Quantity	Unit
1/2" Gypsum Fibre Gypsum Board	20,863	ft2
1/2" Regular Gypsum Board	153,357	ft2
1/8" Polyethylene	18,562	ft2
1/4" Polyethylene	77,325	ft2
Aluminium	7.96	Ton
Ballast (aggregate stone)	461,541	lbs
Batt. Fiberglass	1,090,937	ft2 (1")
Blown Cellulose	488,321	ft2 (1")
Cold Rolled Sheet	1.49	Ton
Concrete 2,900 psi (flyash av)	566,931	ft3
Concrete 4,300 psi (flyash av)	16,910	ft3
Concrete Blocks	22,423	Blocks
Concrete Brick	75,745	ft2
EPDM membrane	215.56	lbs
Galvanized Decking	27.08	Ton
Galvanized Sheet	1.24	Ton
Glazing Panel	24.48	Ton
Hollow Structural Steel	331.66	Ton
Joint Compound	17.81	Ton
Large Dimension Softwood Lumber, kiln-dried	7,702	ft3
Mortar	7,141	ft3
Nails	4.24	Ton
Open Web Joists	21.11	Ton
Paper Tape	0.20	Ton
PVC membrane	36,975	lbs
Rebar, Rod, Light Sections	1,384	Ton
Screws Nuts & Bolts	10.59	Ton
Small Dimension Softwood Lumber, Green	7,230	ft3
Small Dimension Softwood Lumber, kiln-dried	269.73	ft3
Softwood Plywood	253,738	ft2 (3/8")
Solvent Based Alkyd Paint	0.93	usgal
Welded Wire Mesh / Ladder Wire	1.81	Ton
Wide Flange Sections	113.75	Ton

4. Summary Measures

Below are the summary measures of the FSC. Some of the measurements may be at first difficult to understand. However, it is important to consider the units in which the measurements are. Global warming potential for example, is measured in kg CO_2 production per kg of material in the building. CO_2 is considered a major cause of global warming. In order to have any real understanding of the implications of the FSC, and what these numbers mean, further research in each area is required. It is also important to remember that in an LCIA there is uncertainty. In the next section, some of the uncertainties in the analysis are discussed.

Table 4: Summary measures of the FSC



Material ID	Foundations	Walls	Beams & Columns	Roofs	Floors	Extra Basic Mater	Total
Primary Energy Consumption MJ	3,023,185	13,633,363	8,594,564	32,262,900	11,715,136	8,107,571	77,336,718
Weighted Resource Use kg	4,334,495	8,089,538	1,977,831	23,287,305	10,969,524	1,522,179	50,180,872
Global Warming Potential (kg CO2 eq / kg)	707,055	2,166,320	840,251	4,536,598	2,010,017	1,145,448	11,405,689
Acidification Potential (moles of H+ eq / kg)	469,949	1,428,890	453,082	2,857,486	1,287,243	688,194	7,184,843
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	351,240	1,082,388	417,884	2,252,054	998,854	584,425	5,686,846
Eutrophication Potential (kg N eq / kg)	13,861	74,310	31,675	124,949	46,737	31,553	323,085
Ozone Depletion Potential (kg CFC-11 eq / kg)	350,302	1,078,172	417,227	2,246,316	996,538	583,990	5,672,545
Smog Potential (kg NOx eq / kg)	352,082	1,082,019	417,910	2,255,045	1,001,200	585,253	5,693,509

4.1.Uncertainty

Some of the uncertainty involved in the LCA of the FSC includes such things as uncertainty in the life times of the substances, unknown characteristic factors, the use of several characteristic factors within one category, and regional differences. Below, is a more detailed list of some of the uncertainties inherent within the LCA study (Huijbregts et al).

- Linear weighted average to compute impact. Software such as Athena EIE use average weighted values of products to come up with an environmental score. However, this method risks minimizing impacts that may be significant within the context of the construction project but very small when compared to the reference data. Rogers et al)
- Not designed to analyze specific products. A building may use Portland cement which would have different properties then another type of cement. The location of

each different type of cement would also affect the impact of that product. The further away, the longer it has to travel, the more fuel is burned to move it, etc.

- Linear proportionality in production. TRACI assumes that the impact of a product grows linearly as the amount of that product used is increased. This creates a problem since there is economy of scale and it ignores capacity constraints.
- Lack of detailed information. Certain sectors may be reluctant to make their data publicly available. Take for example nickel-hydrate batteries. The specific data may not be there, and in the end we may have to be content with a single rechargeable battery.(Hendrickson et al 43)
- Imported products. It is much more difficult to come up with accurate analysis of products that are imported. This is due to a variety of reasons, unknown climate, work conditions, method of internal transportation. Some LCIAs assume internal country data. For example, 1000lbs of steel was brought from China. However, when entered in the LCIA software, it assumes it was manufactured and produced in North America.

4.2.Sensitivity Analyses

Five materials were chosen: PVC membrane, softwood plywood, fiberglass batt, glazing panel, and 2,900 psi concrete. The materials were then increased by 10% (by weight) to see the effects on the summary measures. Below are the results for the 10% increase by weight of each of the five different materials. Certain measurements are based on global effects. The global warming potential and the ozone depletion potential are both based on the effects they have globally. However, such measurements as the acidification potential are much more significant on a regional scope. It is important to understand that it every measurement was assumed to be at a non-regionalized North American level, and that some uncertainty is involved when assuming this.

4.2.1. PVC membrane

Increasing the PVC membrane by 10% had little effect on anything except the primary energy consumption. However, even that was small with an increase of only 0.18%. This is not surprising since PVC membrane was not a large contributor to the FSC's BoM.

Table 5: Effects of an extra 10% PVC membrane

	Summary	Extra 10% PVC membrane	% Difference
	Total effects	Total effects	Total effects
Primary Energy Consumption MJ	77,336,718	77,475,444	0.18
Weighted Resource Use kg	50,180,872	50,185,186	0.01
Global Warming Potential (kg CO2 eq / kg)	11,405,689	11,413,878	0.07
Acidification Potential (moles of H+ eq / kg)	7,184,843	7,192,168	0.10
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	5,686,846	5,690,782	0.07
Eutrophication Potential (kg N eq / kg)	323,085	323,553	0.14
Ozone Depletion Potential (kg CFC-11 eq / kg)	5,672,545	5,676,473	0.07
Smog Potential (kg NOx eq / kg)	5,693,509	5,697,452	0.07

4.2.2. Softwood Plywood

Increasing the softwood plywood by 10% also did not have a significant impact on any of the summary measures. It did, however, cause at least a 0.19% increase for everything but the weighted resource use. The most significant impact was the 0.35% increase in eutrophication potential. Energy consumption was also significantly increased, though not as much, increasing by 0.29%. However, percentage increased is slightly misleading as the energy consumed during the construction of the building as a whole is quite large. When looking at the actual numbers, using 10% more softwood plywood caused an increase of 226,454 MJ of energy.

Table 6: Effects of an extra 10% softwood plywood

	Summary	Extra 10% Plywood	% Difference
	Total effects	Total effects	Total effects
Primary Energy Consumption MJ	77,336,718	77,563,172	0.29
Weighted Resource Use kg	50,180,872	50,216,843	0.07
Global Warming Potential (kg CO2 eq / kg)	11,405,689	11,427,329	0.19
Acidification Potential (moles of H+ eq / kg)	7,184,843	7,198,964	0.20
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	5,686,846	5,697,463	0.19
Eutrophication Potential (kg N eq / kg)	323,085	324,225	0.35
Ozone Depletion Potential (kg CFC-11 eq / kg)	5,672,545	5,683,134	0.19
Smog Potential (kg NOx eq / kg)	5,693,509	5,704,105	0.19

4.2.3. Fiberglass Batt

Increasing the fiberglass batt by 10% had very impacts of similar significance to that caused by increasing the softwood plywood by 10%. Like softwood plywood, the most noticeable increase was in eutrophication potential with a 0.47% change. Like softwood plywood, everything increased by at least 0.19% except the weighted resource use. Again, it is still important to realize that the magnitude of the increase is still significant with an additional 182,929 kg of resources being used.

Table 7: Effects of an extra 10% Batt Fiberglass

	Summary	Extra 10% Fiberglass	% Difference
	Total effects	Total effects	Total effects
Primary Energy Consumption MJ	77,336,718	77,519,647	0.24
Weighted Resource Use kg	50,180,872	50,197,217	0.03
Global Warming Potential (kg CO2 eq / kg)	11,405,689	11,428,278	0.20
Acidification Potential (moles of H+ eq / kg)	7,184,843	7,200,044	0.21
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	5,686,846	5,697,761	0.19
Eutrophication Potential (kg N eq / kg)	323,085	324,600	0.47
Ozone Depletion Potential (kg CFC-11 eq / kg)	5,672,545	5,683,362	0.19
Smog Potential (kg NOx eq / kg)	5,693,509	5,704,342	0.19

4.2.4. Glazing Panel

Increasing the glazing panel by 10% had very little impact on the total effects. Like the previous three increases in materials, the most significant increase was in eutrophication potential, with an increase of 0.10%.

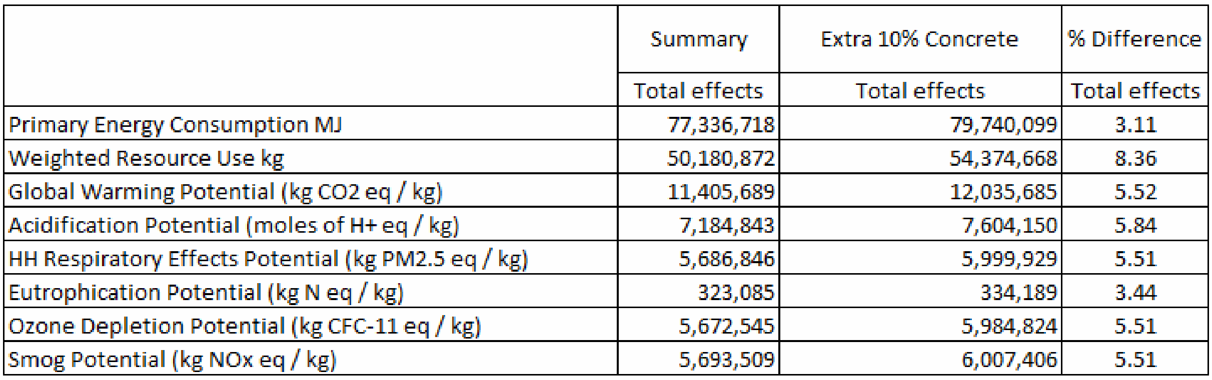
Table 8: Effects of an extra 10% glazing panel

	Summary	Extra 10% Glazing	% Difference
	Total effects	Total effects	Total effects
Primary Energy Consumption MJ	77,336,718	77,346,598	0.01
Weighted Resource Use kg	50,180,872	50,185,181	0.01
Global Warming Potential (kg CO2 eq / kg)	11,405,689	11,412,458	0.06
Acidification Potential (moles of H+ eq / kg)	7,184,843	7,190,045	0.07
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	5,686,846	5,690,292	0.06
Eutrophication Potential (kg N eq / kg)	323,085	323,411	0.10
Ozone Depletion Potential (kg CFC-11 eq / kg)	5,672,545	5,675,940	0.06
Smog Potential (kg NOx eq / kg)	5,693,509	5,696,924	0.06

4.2.5. Concrete (2,900 psi)

Increasing the 2,900 psi concrete by 10% (by weight) had the most significant impact of any of the five materials. In every measurement there was increases of at least 3.11% with the largest being an increase of 8.36% in weighted resources. This makes sense that an increase in concrete would have such a significant effect. Concrete was one of the most used products in the FSC. Every floor, multiple columns, some walls, and even parts of the roof were made of concrete.

Table 9: Effects of an extra 10% concrete



	Summary	Extra 10% Concrete	% Difference
	Total effects	Total effects	Total effects
Primary Energy Consumption MJ	77,336,718	79,740,099	3.11
Weighted Resource Use kg	50,180,872	54,374,668	8.36
Global Warming Potential (kg CO2 eq / kg)	11,405,689	12,035,685	5.52
Acidification Potential (moles of H+ eq / kg)	7,184,843	7,604,150	5.84
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	5,686,846	5,999,929	5.51
Eutrophication Potential (kg N eq / kg)	323,085	334,189	3.44
Ozone Depletion Potential (kg CFC-11 eq / kg)	5,672,545	5,984,824	5.51
Smog Potential (kg NOx eq / kg)	5,693,509	6,007,406	5.51

5. Building Performance

5.1. Payback Period of Improvements

In the figure below you can see that improvements following the minimum Residential Environmental Assessment Program's (REAP) R-values would have a zero payback period. This means that the difference between the energy the FSC is consuming now and if it was improved, is less than the energy required to improve insulation throughout the building. The easiest way to reduce energy loss would be to reduce the amount of windows to the outside. However, this is usually not a popular choice among users of a building. Windows R-values are more than four times smaller than that of walls and roofs. Therefore, the most improvement would occur when dealing with window openings. Other things that could reduce the energy loss would be to add thicker insulation. This option would not require a lot of additional energy to produce, but would have significant savings over time.

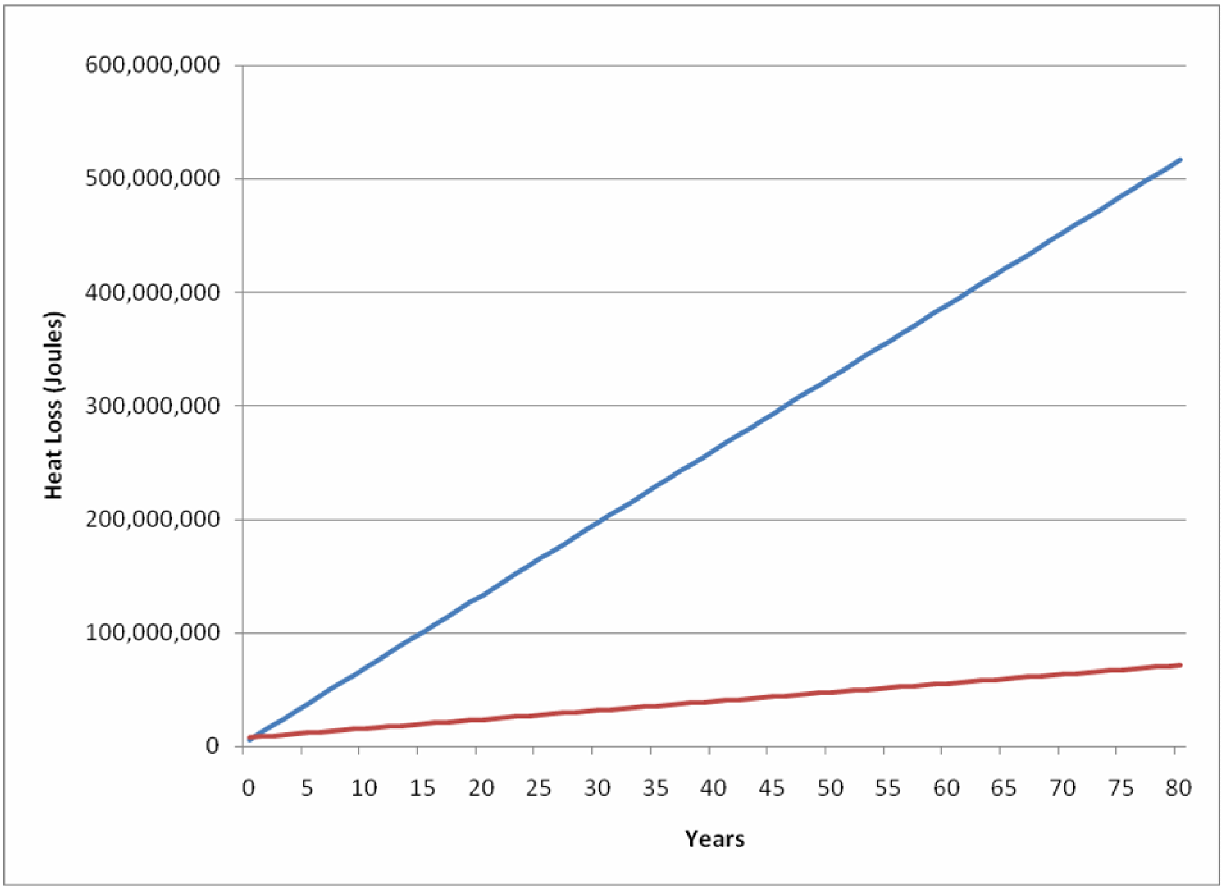


Figure 4: Payback period to update FSC

The above figure shows that it makes sense no matter what the life of the building is to improve the FSC according to REAP's insulation standards. The improvements would reduce the annual energy consumption of the FSC by 5,500,000 Mega Joules. After 20 years there would be a difference of more than 100,000,000 MJ between the current consumption and the improved consumption of energy. Things to consider if the FSC was going to upgrade the envelope system would be a more intensive energy analysis. This is only a brief summary of the potential in energy savings for the FSC if improvements are made. There are still some uncertainties within the measurements. However, the potential for energy savings will still be significant no matter how accurate the model is. Other ways to improve the accuracy is through a more intensive LCA to measure tradeoffs (i.e. creating lots of gypsum window waste, manufacturing insulation & windows), logistics (i.e. how would you actually renovate the building), and the economic costs of the upgrades to prove that they are necessary. With rising energy costs, it only makes sense to upgrade the FSC envelopes.

Other easy ways to reduce the energy consumption of the FSC would be to install high efficiency appliances and fluorescent lighting. Reducing the lighting throughout the FSC could also have the potential to reduce energy consumption.

6. Conclusion

The LCA of the FSC determined that the primary energy consumption was 77,336,718 MJ and the amount of resources used by weight was 50,180,872kg. When considering the FSC, it consumed approximately 400 MJ/ft^2. Other numbers that were significant was the global warming potential of 11,405,689 kg CO_2 eq/kg and the ozone depletion potential of 5,672,545 kg CFC-11 eq/ kg. Manufacturing the products consumed significantly more energy than construction, but used approximately half of the weighted resources. Construction played a much more significant impact on the global warming potential and the ozone depletion potential.

Concrete played one of the most significant roles in energy consumption in the construction of the FSC, and it can be one of the easiest to reduce with the introduction of such things as green concrete (concrete with significantly more fly ash then regular concrete). LCA’s are incredibly complex, and while this study was brief in time, many assumptions were made, and many uncertainties occur within the LCA and the IE. The overall energy consumption and impact of the FSC is given in the report, and is made transparent through the documents in Appendices A and B. It will be most useful in comparing to other buildings of similar (and different) usage and size. This project and course only begin to explore what can be accomplished and achieved with this software. Further investigation can bring forth even more accurate results and can continue to help in the growing understanding of buildings and how to improve the impacts they possess.

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Appendix A: Impact Estimator Input Tables

Below is the data that was collected for the FSC and how it was inputted into the IE.

				Ideal	**Input**
1 Foundation					
	1.1 Slab on Grade				
		1.1.1 Concrete Slab on Grade			
			Length (ft)	98.4	98.4
			Width (ft)	78.72	78.72
			Thickness (ft)	0.492	0.492
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
	1.2 Concrete Footing				
		1.2.1 F1			
			Length (ft)	4.592	4.592
			Width (ft)	3.28	3.28
			Thickness (ft)	0.656	0.656
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	10M	10M
		1.2.2 F2			
			Length (ft)	4.92	24.6
			Width (ft)	4.92	4.92
			Thickness (ft)	1.148	1.148
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	15M	15M
		1.2.3 F3			
			Length (ft)	7.872	23.616
			Width (ft)	7.872	7.872
			Thickness (ft)	1.476	1.476
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.4 F4			
			Length (ft)	6.56	13.12
			Width (ft)	6.56	6.56
			Thickness (ft)	1.312	1.312
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE

			Rebar	20M	20M
		1.2.5 F5			
			Length (ft)	7.216	21.648
			Width (ft)	7.216	7.216
			Thickness (ft)	1.476	1.476
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.6 F6			
			Length (ft)	5.576	16.728
			Width (ft)	5.576	5.576
			Thickness (ft)	0.984	0.984
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.7 F7			
			Length (ft)	5.904	47.232
			Width (ft)	5.904	5.904
			Thickness (ft)	1.312	1.312
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.8 F8			
			Length (ft)	9.184	110.208
			Width (ft)	9.184	9.184
			Thickness (ft)	1.804	0.902
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.9 F9			
			Length (ft)	5.904	41.328
			Width (ft)	6.232	6.232
			Thickness (ft)	1.148	1.148
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.10 F10			
			Length (ft)	5.904	5.904
			Width (ft)	5.904	5.904
			Thickness (ft)	1.148	1.148
			Concrete (psi)	3600	2900

			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.11 F11			
			Length (ft)	4.92	78.72
			Width (ft)	4.92	4.92
			Thickness (ft)	1.968	0.984
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.12 F12			
			Length (ft)	6.888	55.104
			Width (ft)	3.936	3.936
			Thickness (ft)	0.82	0.82
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	10M	10M
		1.2.13 F13			
			Length (ft)	3.936	7.872
			Width (ft)	3.936	3.936
			Thickness (ft)	1.312	1.312
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	15M	15M
		1.2.14 F14			
			Length (ft)	12.792	12.792
			Width (ft)	5.904	5.904
			Thickness (ft)	1.312	1.312
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	15M	15M
		1.2.15 F15			
			Length (ft)	11.808	23.616
			Width (ft)	3.936	3.936
			Thickness (ft)	2.296	1.148
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	15M	15M
		1.2.16 F16			
			Length (ft)	10.168	20.336
			Width (ft)	3.28	3.28
			Thickness (ft)	2.624	1.312

			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.17 F20			
			Length (ft)	29.52	29.52
			Width (ft)	29.52	29.52
			Thickness (ft)	3.28	3.28
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.2.18 F21			
			Length (ft)	39.032	78.064
			Width (ft)	39.032	39.032
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.19 F22			
			Length (ft)	22.96	45.92
			Width (ft)	22.96	22.96
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.20 F23			
			Length (ft)	36.08	72.16
			Width (ft)	19.68	19.68
			Thickness (ft)	2.952	1.476
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.21 F24			
			Length (ft)	29.192	58.384
			Width (ft)	29.192	29.192
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.22 F25			
			Length (ft)	132.512	265.024
			Width (ft)	66.256	66.256

			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.23 F27			
			Length (ft)	29.192	58.384
			Width (ft)	29.192	29.192
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.24 F28			
			Length (ft)	31.16	62.32
			Width (ft)	31.16	31.16
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.25 F29			
			Length (ft)	13.12	39.36
			Width (ft)	42.64	42.64
			Thickness (ft)	3.936	1.312
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.26 F31			
			Length (ft)	28.864	57.728
			Width (ft)	28.864	28.864
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.27 F32			
			Length (ft)	22.96	45.92
			Width (ft)	22.96	22.96
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.28 F33			
			Length (ft)	45.92	91.84

			Width (ft)	13.12	13.12
			Thickness (ft)	3.28	1.64
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.29 CF1			
			Length (ft)	7.872	23.616
			Width (ft)	7.872	7.872
			Thickness (ft)	3.936	1.312
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	25M	20M
		1.2.30 CF2			
			Length (ft)	5.904	11.808
			Width (ft)	2.952	2.952
			Thickness (ft)	2.952	1.476
			Concrete (psi)	3600	2900
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	15M	15M
	1.3 Slab on Grade Concrete Pad				
		1.3.1 CP1			
			Length (ft)	44.28	44.28
			Width (ft)	44.28	44.28
			Thickness (ft)	0.328	0.328
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
	1.4 Concrete Strip Footing				
		1.4.1 F30			
			Length (ft)	262.4	262.4
			Width (ft)	6.56	6.56
			Thickness (ft)	1.968	1.968
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
		1.4.2 SF1			
			Length (ft)	49.2	49.2
			Width (ft)	3.28	3.28
			Thickness (ft)	0.984	0.984
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M

		1.4.3 SF2			
			Length (ft)	557.6	557.6
			Width (ft)	2.296	2.296
			Thickness (ft)	0.984	0.984
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	15M	15M
		1.4.4 SF3			
			Length (ft)	32.8	32.8
			Width (ft)	3.936	3.936
			Thickness (ft)	0.984	0.984
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Rebar	20M	20M
2 Walls					
	2.1 Concrete Block Wall				
		2.1.1 W1			
			Wall Type	Basement	Basement
			Length (ft)	859.36	859.36
			Height (ft)	13.94	13.94
		Openings	Total opening area (ft^2)	0	0
			Doors	39.36	39.36
			Category	-	Cladding
			Material	-	Brick
			Type	-	(metric) Modular
		2.1.2 W2			
			Wall Type	Basement	Basement
			Length (ft)	377.2	377.2
			Height (ft)	21.4512	21.4512
		Openings	Total opening area (ft^2)	0	0
			Doors	13.12	13.12
			Category	-	Cladding
			Material	-	Brick
			Type	-	(metric) Modular
		2.1.3 W3			
			Wall Type	Basement	Basement
			Length (ft)	747.84	747.84
			Height (ft)	7.97696	7.97696
		Openings	Total opening area (ft^2)	0	0
			Doors	0	0
			Category	-	Cladding

			Material	-	Brick
			Type	-	(metric) Modular
		2.1.4 W4			
			Wall Type	Ground Floor	Ground Floor
			Length (ft)	1876.16	1876.16
			Height (ft)	16.4	16.4
		Openings	Total opening area (ft^2)	2766.348	2766.348
			Doors	32	32
			Category	-	Cladding
			Material	-	Brick
			Type	-	(metric) Modular
	2.2 Wood Walls				
		2.2.1 W5			
			Wall Type	Second - Fourth (Inside)	Second - Fourth (Inside)
			Length (ft)	1207.04	1207.04
			Height (ft)	13.94	13.94
		Openings	Total opening area (ft^2)	0	0
			Doors	20	20
			Category	-	Cladding
			Material	-	Brick
			Type	-	(metric) Modular
	2.3 Conrete Brick Walls				
		2.3.1 W6			
			Wall Type	Second - Fourth (Outside)	Second - Fourth (Outside)
			Length (ft)	1823.68	1823.68
			Height (ft)	16.4	16.4
		Openings	Total opening area (ft^2)	10957.752	10957.752
			Doors	0	0
			Category	-	Cladding
			Material	-	Brick
			Type	-	(metric) Modular
	2.4 Wood Walls				
		2.4.1 W7			
			Wall Type	Ground Floor	Ground Floor
			Length (ft)	1617.04	1617.04
			Height (ft)	16.4	16.4
		Openings	Total opening area (ft^2)	0	0
			Doors	42	42
		Door Opening Envelope	Category	-	Insulation
			Material	-	Fiberglass
			Type	-	batt

			Thickness	-	140
		2.4.2 W8 (w/ Veneered Face)			
			Wall Type	Second - Fourth (Inside)	Second - Fourth (Inside)
			Length (ft)	11653.84	11653.84
			Height (ft)	13.94	13.94
		Openings	Total opening area (ft^2)	0	0
			Doors	381	381
		Door Opening Envelope	Category	-	Insulation
			Material	-	Fiberglass
			Type	-	batt
			Thickness	-	140
			Category	-	Vapour barrier
		2.4.3 W9 (Curtain Wall)			
			Length (ft)	90	90
			Height (ft)	59	59
			Doors	1	1
3 Mixed Columns & Beams					
	3.1 Concrete Column/Beams				
		3.1.1 C1			
			Number of bays per row	8	8
			Number of rows	2	2
			Floor to floor height (ft)	13.94	13.94
			Bay sizes (ft)	14.76	14.76
			Supported span (ft)	19.68	19.68
			Live load (psi)	0.7	0.7
		3.1.2 C2			
			Number of bays per row	9	9
			Number of rows	3	3
			Floor to floor height (ft)	21.4512	21.4512
			Bay sizes (ft)	10.824	10.824
			Supported span (ft)	27.88	27.88
			Live load (psi)	0.7	0.7
		3.1.3 C3			
			Number of bays per row	7	7
			Number of rows	1	1
			Floor to floor height (ft)	7.9376	7.9376
			Bay sizes (ft)	17.056	17.056
			Supported span (ft)	25.584	25.584
			Live load (psi)	0.7	0.7
		3.1.4 C4			
			Number of bays per row	12	12

			Number of rows	13	13
			Floor to floor height (ft)	31.242	31.242
			Bay sizes (ft)	15.5144	15.5144
			Supported span (ft)	17.876	17.876
			Live load (psi)	0.35	0.35
		3.1.5 C5			
			Number of bays per row	12	12
			Number of rows	12	12
			Floor to floor height (ft)	31.242	31.242
			Bay sizes (ft)	15.5144	15.5144
			Supported span (ft)	19.352	19.352
			Live load (psi)	0.35	0.35
		3.1.6 C6			
			Parallam Columns (ft^3)	-	162
			Volume of Wood (ft3)	-	6822
4 Floors					
	4.1 Concrete Floors				
		4.1.1 FL1			
			Width (ft)	366.376	4474.4
			Length (ft)	366.376	30
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Thickness (ft)	0.492	0.492
			Rebar	15M	15M
			Category	-	Gypsum board
			Material	-	Gysum
			Type	-	Regular 1/2"
		4.1.2 FL2			
			Width (ft)	139.728	650.8
			Length (ft)	139.728	30
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Thickness (ft)	0.492	0.492
			Rebar	20M	20M
		4.1.3 FL3			
			Width (ft)	71.504	170.4
			Length (ft)	71.504	30
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Thickness (ft)	6.56	6.56
			Rebar	20M	20M

			Category	-	Gypsum board
			Material	-	Gysum
			Type	-	Regular 1/2"
5 Roof					
	5.1 Roof				
		5.1.1 R1			
			Width (ft)	667	667
			Span (ft)	26	26
			Live load (psi)	0.5	0.5
			PVC Roofing Membrane (in)	-	13
			Vapour Barrier	-	1/8"
		5.1.2 R2			
			Width (ft)	260.104	307.1
			Span (ft)	35.424	30
			Live load (psi)	0.5	3.6
		5.1.3 R3			
			Width (ft)	135.136	608.7
			Length (ft)	135.136	30
			Concrete (psi)	3600	3600
			Concrete flyash %	AVERAGE	AVERAGE
			Thickness (ft)	0.492	0.492
			Rebar	20M	20M
			PVC Roofing Membrane (in)	-	13
6 Extra Materials					
	6.1 Extra Materials				
		6.1.1 Extra Wood			
			Parallam Columns (Mbfm)	-	134.2
		6.1.2 Steel			
			Steel Staircase (Tons)	-	270

Appendix B Impact Estimator Input Assumptions

Any sub heading without a description did not have any significant assumptions made to calculate the values underneath it.

1 Foundation	The foundation was broken down into a concrete slab on grade, footings, strip footings, and slab on grade concrete pads. The concrete footings and strip footings were named the same as the architectural drawings (i.e. F1, F2…). Any concrete footings not listed in the structural legend were named CF1, CF2, and so on, while any strip footings not listed were named SF1, SF2, and so on. The footings were calculated using the count feature in OnScreen, and the length of the footing was then multiplied by the amount of footings of each type. The IE restricted the height of the footings. If a footing was larger than the allowed height, it was divided by two while the length was multiplied by two. Rebar presented a problem if the reinforcing was greater than 20M bars. The IE only allowed for 10M, 15M, and 20M bars in the footings. Therefore, anything larger than 20M was considered 20M while anything smaller than 10M was considered 10M. The slab on grade was a simple area calculation. The IE only allowed for two thicknesses, and the area was adjusted accordingly to account for this. The concrete pads were not slabs. They were similar to the concrete footings. However, they were only 100mm thick. They were named CP1, CP2, and so on. The concrete was assumed to be 20MPa as no information was given. Fly ash was assumed to be "average", which is an option when entering concrete data in the IE.		
	1.1 Slab on Grade		
		1.1.1 Concrete Slab on Grade	
	1.2 Concrete Footing		
		1.2.1 F1	
		1.2.2 F2	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 5.
			L=(Cited Length)*(# of Footings of That Kind)
			L=(4.92ft)*5
			L=24.6ft
		1.2.3 F3	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 3.
			Similar to 1.2.2 F2
		1.2.4 F4	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 2.
			Similar to 1.2.2 F2

		1.2.5 F5	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 3.
			Similar to 1.2.2 F2
		1.2.6 F6	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 3.
			Similar to 1.2.2 F2
		1.2.7 F7	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 8.
			Similar to 1.2.2 F2
		1.2.8 F8	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 12.
			Similar to 1.2.2 F2
		1.2.9 F9	
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 7.
			Similar to 1.2.2 F2
		1.2.10 F10	
		1.2.11 F11	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 5 and again by 2 to account for the

			thickness being reduced by a division of 2.		
			L=(Cited Length)*(# of Footings of That Kind)*(# Thickness Divided By)		
			L=(4.92ft)*8*2	Note: T = 1.968ft/2 = 0.984ft	
			L=78.72ft		
		1.2.12 F12			
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 8.		
			Similar to 1.2.2 F2		
		1.2.13 F13			
			The length of this footing was adjusted to account for the multiple footings of this type. The measured width and thickness were maintained, however the length was multiplied by 2.		
			Similar to 1.2.2 F2		
		1.2.14 F14			
		1.2.15 F15			
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.		
			Similar to 1.2.11 F11		
		1.2.16 F16			
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.		
			Similar to 1.2.11 F11		
		1.2.17 F20			
		1.2.18 F21			
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.		
			Similar to 1.2.11 F11		

		1.2.19 F22	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.20 F23	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.21 F24	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.22 F25	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.23 F27	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.24 F28	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11

		1.2.25 F29	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 3 to account for the thickness being reduced by a division of 3.
			Similar to 1.2.11 F11
		1.2.26 F31	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.27 F32	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.28 F33	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.
			Similar to 1.2.11 F11
		1.2.29 CF1	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 3 to account for the thickness being reduced by a division of 3.
			Similar to 1.2.11 F11
		1.2.30 CF2	
			The length of this footing was adjusted to account for the multiple footings of this type, and/or because the thickness of the footing did not fall within the limits of the EIE. The measured width was maintained, however the length was multiplied by 2 to account for the thickness being reduced by a division of 2.

			Similar to 1.2.11 F11
	1.3 Slab on Grade Concrete Pad		
		1.3.1 CP1	
	1.4 Concrete Strip Footing		
		1.4.1 F30	
		1.4.2 SF1	
		1.4.3 SF2	
		1.4.4 SF3	
2 Walls	Walls were either concrete block, wood, or concrete brick. However, each wall was labeled W followed by the number in which it was entered (i.e. the first wall was called W1). They were linear measurements, with the height measured from the profile drawings. Floors two through four were the same height, and so walls continuing through these three floors were considered one wall with a height three times the single floor height. Openings included windows and doors. All interior walls were assumed to have no window. Exterior walls were measured by using one meter strips. OnScreen will measure the length of wall accounted for while using a line thickness equal to one meter. For example a 10 meter high wall 5 meters long would have a wall area of 50 meters squared. On OnScreen, 10 one meter strips 5 meters long would be measured. This was done to account for the large windows present throughout the exterior wall. Area conditions were utilized to calculate the percent glazing area for the curtain walls, as well as the areas of the window openings. Windows were not counted directly, but instead the area of openings for windows was determined using the area function, and then divided by an average exterior window size. These assumptions were made so that a reasonable estimate could be made within the timeframe given. Some other assumptions and calculations were made in order to complete modeling of the walls for the FSC building, such as affecting the length of the concrete cast-in-place walls to accommodate the wall thickness limitation in the IE, and the assumption that interior steel stud walls were light gauge (25Ga) and exterior steel stud walls were heavy gauge (20Ga).		
	2.1 Concrete Block Wall		
		2.1.1 W1	
		2.1.2 W2	
		2.1.3 W3	
		2.1.4 W4	
	2.2 Steel Stud Walls		
		2.2.1 W5	
			Since this was an interior wall, 89mm thick Fiberglass Batt was assumed. It is also assumed that it is steel studs throughout the interior walls. No gypsum board was assumed to be present.
	2.3 Conrete Brick Walls		
		2.3.1 W6	
	2.4 Steel Stud Walls		
		2.4.1 W7	
			Since this was an interior wall, 89mm thick Fiberglass Batt was assumed. It is also assumed that it is steel studs throughout the interior walls. No gypsum board was assumed to be present.
		2.4.2 W8 (w/ Veneered Face)	
			Since this was an interior wall, 89mm thick Fiberglass Batt was assumed. It is also assumed that it is steel studs throughout the interior walls. No gypsum board was assumed to be present.

		2.4.3 W9 (Curtain Wall)	
			The total length of the curtain walls were measured linearly from the floor plans. The average height of the FSC was then multiplied by the length to determine an average area. It was assumed that only one door for the east entrance is present.
3 Mixed Columns & Beams	All columns were named C followed by the number in which they were entered (i.e. the first column is C1). The method used to measure column sizing was completely depended upon the metrics built into the IE. That is, the IE calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. A grid system of columns had to be assumed even though it did not necessarily exist. An area that appeared to have a slight order to the column distribution was squared off and averaged for span between columns. For example, the foundation columns were broken into three areas. The main atrium in the FSC is an L-shape. The eight columns in the atrium were assumed to be one long line of columns with the spacing between them averaged as the span and the distance to the surrounding walls averaged as the bay size.		
	3.1 Concrete Column/Beams		
		3.1.1 C1	
			Because of the variability of bay and span sizes, the column bay and span size was estimated using multiple grid systems throughout the FSC.
		3.1.2 C2	
			Because of the variability of bay and span sizes, the column bay and span size was estimated using multiple grid systems throughout the FSC.
		3.1.3 C3	
			Because of the variability of bay and span sizes, the column bay and span size was estimated using multiple grid systems throughout the FSC.
		3.1.4 C4	
			Because of the variability of bay and span sizes, the column bay and span size was estimated using multiple grid systems throughout the FSC.
		3.1.5 C5	
			Because of the variability of bay and span sizes, the column bay and span size was estimated using multiple grid systems throughout the FSC.
		3.1.6 C6	
			Because of the variability of bay and span sizes, the column bay and span size was estimated using multiple grid systems throughout the FSC.
4 Floors	Floors included the roof and were labeled FL# for floors and R# for the roof. There were five floors and one roof for the FSC. However, the roof was broken into three parts to accommodate the three different materials use. The building envelope data was not available for the floors, and therefore average industry standards were assumed. Stairs were assumed to be steel and an area was determined from OnScreen. The average height of the stairs was then multiplied by the area giving a volume. Using online resources, the unit weight of rolled steel was used (7850 kg/m3) and was added to extra base materials. The values given though are fairly accurate since the steel stairs are not a significant part of the FSC. The floors were measured using area conditions. Much like in column and beams, the IE calculated the thickness of the material based on some basic variables regarding the assembly. These include; floor width, span, concrete strength, concrete flyash content and live load. Another assumption that had to be made in this assembly group was setting the concrete strength to 20 MPa, instead of the specified 25 MPa. This was due to the IE's limitation to model only 20 MPa, 30 MPa or 60 MPa concrete strengths. Spans were also limited to no more than 10 meters. If a span was greater than 10 meters, the total area was then divided by 10 meters to determine the resulting length.		

	4.1 Concrete Floors		
		4.1.1 FL1	
			Because of the limitations of the IE, spans were reduced to 30 ft. This was done by maintaining the same floor area, but reducing the span to 30 ft and increasing the length to account for the reduction.
			Sited Span > 30ft
			Area=(Cited Length)*(Cited Span)
			Area=366.376ft*366.376ft
			Area=134,231ft2
			Span =30ft, Length=Area/30ft
			Length=134,231ft2/30ft
			Length=4,474ft
		4.1.2 FL2	
			Because of the limitations of the IE, spans were reduced to 30 ft. This was done by maintaining the same floor area, but reducing the span to 30 ft and increasing the length to account for the reduction.
			Similar to 4.1.1 FL1
		4.1.3 FL3	
			Because of the limitations of the IE, spans were reduced to 30 ft. This was done by maintaining the same floor area, but reducing the span to 30 ft and increasing the length to account for the reduction.
			Similar to 4.1.1 FL1
5 Roof	The roof was modeled using area conditions. The roof of the FSC was split into three catagories, a suspended slab for the main roof, an open web steel joist system, and glazing for the large skylight. Once again the concrete strength was set to 20 MPa instead of the specified 25 MPa. Other than these there were no significant assumptions required to complete the takeoffs for the roof assemblies.		
	5.1 Roof		
		5.1.1 R1	
			Because of the limitations of the IE, spans were reduced to 30 ft. This was done by maintaining the same roof area, but reducing the span to 30 ft and increasing the length to account for the reduction.
			Similar to 4.1.1 FL1
		5.1.2 R2	
			Because of the limitations of the IE, spans were reduced to 30 ft. This was done by maintaining the same roof area, but reducing the span to 30 ft and increasing the length to account for the reduction.
			Similar to 4.1.1 FL1
		5.1.3 R3	

			Because of the limitations of the IE, spans were reduced to 30 ft. This was done by maintaining the same roof area, but reducing the span to 30 ft and increasing the length to account for the reduction.
			Similar to 4.1.1 FL1
6 Extra Materials	The large Parallam columns within the FSC are not supporting any significant load. The only loads that they are supporting are the additional beams. Their main purpose is aesthetics only. When entering the Parallam column grid into the EIE, the loads that the columns are calculated to take would be greatly exaggerated. Since the Parallam columns are not used for structural support, they were added to extra base material. The length calculator in OnScreen was used and the columns were then multiplied by their average thickness. To account for uncertainty, an additional 5% was added. The steel staircases were also difficult to model in the IE, and therefore (as explained in floors), the area count was used in OnScreen to determine the total surface area of steel staircases throughout the FSC. Using the archeticual drawings, the average height of the steel staircases was then determined and multiplied by the surface area. The unit weight of rolled steel was used (7850 kg/m3) to determine the total weight of additional steel within the FSC.		
	6.1 Extra Materials		
		6.1.1 Extra Wood	
			See discription above
		6.1.2 Steel	
			See discription above