UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Life Cycle Assessment Report Chemistry Building UBC

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PROVISO

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 posting of this report.

If further information is required or if you would like to include details from this study in your research please contact rob.sianchuk@gmail.com.

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Abstract

This life cycle assessment of the Chemistry building at the University of British Columbia is an study to analyze environmental impacts. The information gathered in this study will be used to make future sustainable decisions at UBC. The scope of this study only includes the manufacturing and construction phases, also known as Cradle-to-gate analysis. OnScreen takeoff and Athena's Impact Estimator were used to model and catalogue the materials and impacts from the Chemistry building. An output from the Impact Estimator is the bill of materials, which encompasses all the material quantities. The environmental effects of the materials are then studied to determine what impacts the Chemistry building had during it's initial life stages. A sensitivity analysis was also performed to understand what effect each of the top five most used materials individually have on the environment. This analysis highlights which materials should be switch for alternatives in order to mitigate environmental impacts. Lastly a building performance model was used to investigate what effects improving the building's envelope would have. This model compares the current envelope system to a system that meets a UBC standard and investigates how long the building would have to be in operation to see a return on the initial building envelope improvements.

1.0 Introduction

The construction for the Chemistry building at the University of British Columbia started in 1914. The cost of the original structure was $79,800.00. It was originally designed for chemistry alone but ended up housing physics, bacteriology and public health. The main structural skeleton of the building is concrete and the exterior is a built from granite and other field stone in a Tudor style. The architectural drawings for the original building include: 2 large lecture theaters, 4 large lecture rooms, 8 large chemistry labs, 3 large physic labs, 3 large biology labs, 15 research and private labs, 4 balance rooms, 7 lab offices, 4 workshops, 2 dark rooms, 2 light labs, 3 supply rooms and various other specific rooms, such as liquid air rooms, sterilizing rooms etc. The chemistry building was the original science building on the UBC campus. It housed majority of the labs and large lecture halls at its time of construction.

Building System	Chemistry Building's Specific Characteristics
Structure	Concrete structure with concrete columns and beam suspending concrete slabs
Floors	Basement: Concrete slab on grade; Ground, First, Second and Floors: Suspended concrete slabs
Exterior Walls	Foundation walls: Cast in place walls; Basement, Ground, Second and Third Floors: Brick but modeled with concrete cinder blocks, stone exterior cladding.
Interior Walls	Basement: plaster on brick, modeled with stucco and concrete cinder blocks; Ground, First, Second and Third Floors: plaster on brick, modeled with stucco on concrete cinder blocks
Windows	All windows:leaded single pain
Roof	All roofs: 4 ply Built up Asphalt Roof System – inverted, with Rock-wool glass felt at a thickness of 8”.

Table 1: Chemistry Building's Characteristics

2.0 Goal of Study

This life cycle analysis (LCA) of the Chemistry Building at the University of British Columbia was carried out as an exploratory study to determine the environmental impact of it's design. This LCA of the Chemistry building is also part of a series of twenty-nine 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 Chemistry building. An exemplary application of these references are in the assessment of potential future performance upgrades to the structure and envelope of the Chemistry building. When this study is considered in conjunction with the twenty-nine 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 Chemistry building 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 are 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.

3.0 Scope of Study

The product system being studied in this LCA are the structure and envelope of the Chemistry building 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 Chemistry building, as well as associated transportation effects throughout.

3.1 Tools, Methodology and Data

Two main software tools are to be utilized to complete this LCA study; OnCenter's OnScreen TakeOff 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 Appendices A and B respectively.

Using the formatted takeoff data, version 4.0.64 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 Chemistry building 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 (inclusive of raw material extraction), transportation of construction materials to site and their installation as structure and envelope assemblies of the Chemistry building. As this study is a cradle-to-gate assessment, the expected service life of the Chemistry building 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 Chemistry building, 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 Chemistry building. 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 generates a rough estimate of the energy payback period of investing in a better performing envelope.

The primary sources of data used in modeling the structure and envelope of the Chemistry building are the original architectural and structural drawings from when the was initially constructed in 1915. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as their associated envelope and/or openings (ie. doors and windows). 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 bill of materials and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further as they emerge in the Building Model section of this report and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Appendix B.

4.0 Modeling

To model the chemistry building the materials quantities need to be attained from the architectural drawings. The architectural plans of the original Chemistry building were drawn by hand in 1914. The drawings in some instances were quite hard to read and follow. Being hand drawn there are errors and corrections which can be quite confusing. The scanned drawings, almost a century old, were often blurry and even had tares in some areas. From these challenges it was difficult to comprehend the drawings at times, but by using computer software it was not a insurmountable task. OnScreen takeoff is a computer program that was used to extract quantities of materials. Linear conditions were used to model wall systems, area conditions for floors and count conditions for windows, doors, columns and beams. This allowed any easy method to obtain values and organize the building components. The components were organized into six main categories: foundations, walls, columns and beams, floors, roof and extra materials. Within these categories, subcategories were used to organize components based on their purpose within the building's structure; then furthermore an identifying attribute is added to distinguish between other similar components. An example would be, Footing_Thickness 2', which would be within the foundations category. Within each category and subcategory certain assumptions were needed to be made due to information not being found on the drawings as well as assumptions to decide on surrogate materials to be used to model actual materials, such as concrete blocks for brick. The assumptions and methodologies for each category are described below.

4.7 Foundations

Foundations were split into 2 categories, slab on grade and footings. Stairs for the entire building were also slotted into this category since in the Impact Estimator (IE) foundation inputs are the only area in the software where rebar specifications can be added. For slab on grade the covered area was determined from the area condition and assumptions were made that the concrete strength was 3000 psi, that fly ash was average and that a 3 mil polyethylene vapour barrier was used. Some calculations were required to adjust the slab thickness to the possible values of 4 inches and 8 inches in the IE. The footings were also modeled with a area condition and included assumptions that concrete was 4000 psi and that fly ash was average. Calculations were done to adjust the width of the footings to accommodate the limitation of footing thickness to be under 19.7 inches. Lastly stairs were modeled using the linear and area condition to determine the amount of concrete. Since the stairs were presented in various ways throughout the plans it was difficult to model and therefore both linear and area conditions were required. To model certain stair locations, excess thickness needed to be added to the area conditions to account for the extra material caused be elevation changes rather than just the area from a top view. The main assumptions with the stairs were that fly ash is average and concrete strength is 3000 psi.

4.2 Walls

The two subcategories for walls are based on the materials and methods used to construct the walls, being cast in place and concrete block. Cast in place walls were modeled using the linear conditions and were grouped together by their specific height. Assumptions that were included in the modeling process are that fly ash is average, concrete strength is 3000 psi and that a 3 mil polyethylene vapour barrier is present. Also since the IE didn't have the option of #4 rebar so #5 rebar was used in its place. Some calculation was also required to adjust the 1 foot 4 inch thick wall into the allocated value of 12 inches in the IE. Concrete block walls were also modeled using the linear condition and were organized by corresponding floors. The main assumption that was made for this wall type was that an appropriate surrogate for brick walls is concrete cinder block, with a standard with of 8 inches. For walls that were wider than 8 inches, the length of the wall was adjusted to account for the extra material. Other assumptions were that the rebar was #4, there was a 3 mil polyethylene vapour barrier, stucco was used in place of plaster on all interior surfaces and that the stone cladding was represented by stone aggregate in the extra basic materials section, section 4.6.

4.3 Columns and Beams

To model columns and beams the method depended on the metrics of the Impact Estimator. The IE calculates the size of columns and beams based on parameters such as floor to floor height, bay size, span width, live load and the number of columns and beams. Since the drawings did not specify the live load of the buildings it was assumed to be 75 psf, which is appropriate for an institutional structure.

4.4 Floors

The floors were modeled using the area condition. Once the floor area was calculated but the span and with of the floor need to be designated to be entered into the Impact Estimator. The calculation was to divide the total area of all similar floors by the most common span size. Assumptions that were that the concrete strength was 3000 psi, the live loading was 75 psf and that fly ash was average.

4.5 Roof

Modeling the roof required the surface area to be calculated with the area condition. To enter the roof materials into the Impact estimator the width and span of the roof were required. To calculate the width the total roof area was divided by the most common span. The main assumption for this component was the roof system used. The assumed material was a 4 ply Built up Asphalt Roof System – inverted, with Rockwool glass felt at a thickness of 8”. It was also assumed that a 3 mil polyethylene vapour barrier. Material selection was a big unknown since nothing was mentioned in the architectural plans.

4.6 Extra Basic Materials

To model the stone cladding on all the exterior walls, ballast, or stone aggregate, was used as a surrogate. Since stone aggregate is manufactured and transported in a similar manner to stone bricks it is an appropriate surrogate. The surface area of each exterior wall was measured, this value is multiplied by the thickness of stone and then multiplied by the density to determine the mass of stone required. The assumed density for standard stone was 156.9 lbs/ft^3.

More information and details for the assumptions listed in the above components, as well as details on the material adjustment calculations, can be found in

Appendix B, the Impact Estimator Assumptions Document. All adjusted values and assumptions that were entered into the the Impact estimator can be found in the Impact Estimator Inputs Document, Appendix A.

5.0 Bill of Materials

Entering the material quantities in the Impact Estimator, a bill of materials is produced. The bill of materials lists the quantities, in metric units, of all of construction materials that were used to construct the Chemistry Building. The highlighted rows in the following list of materials are the five greatest quantities of materials in the Chemistry Building.

Ballast, or stone aggregate, is the largest quantity of materials used in the Chemistry building. The use of ballast is required for the roof envelope and for the stone cladding on the exterior walls. The assumption that the roof system is made from a 4 ply Built up, inverted, Asphalt Roof System creates a substantial requirement for ballast. Since no information on the roof system was given, this is a large assumption which may be an over estimation of the ballast material required. To model the stone exterior, ballast was added as an extra base material. The use of crushed stone, ballast, compared to stone bricks is a close surrogate. Using ballast as a surrogate for stone brick probably has little effect on the estimation of material.

Concrete cinder blocks are the next largest quantity of material used. Concrete blocks were used as a surrogate for the bricks that were expressed in the drawings. All of the exterior and interior walls were modeled using concrete blocks. This assumption that all walls, except for the cast in place foundations, are concrete block, cause this value to be quite large. The use of this surrogate material should have little effect on the estimation of materials required.

Another of the five greatest quantities is 20 MPa concrete. This concrete was used to model all concrete components other than the footings, which were modeled at 30 MPa. It was assumed that majority of the concrete used in 1914 was of lower strength than the standard of 30 MPa used today. This assumption may have been an under estimate on the amount of cement added to the concrete, which would under estimate the most energy intensive part of concrete. However, when inputting concrete strength for beam and column design, using 20 MPa may have caused these components to be sized larger than if 30 MPa concrete was used. This would increase the volume of concrete required, over estimating the total amount in the materials list.

Roofing asphalt is also one of the five greatest quantities used. This material is also part of the 4 ply Built up, inverted, Asphalt Roof System. This system was assumed to be used since no actual roof system was specified in the drawings. Therefore this may be a great over estimation since it may not be present in such quantities, if another roof system was actually used, such as a PVC Membrane system.

Lastly rebar completes the five greatest quantities of materials. Rebar was modeled in all concrete components as well as the concrete block walls. The use in the concrete block wall may cause an overestimation since it is not clear on the drawings whether rebar is used to tie the brick walls together. One could assume that such measures where taken, but this again leaves the possibility of an overestimation.

Material	Quantity	Unit
#15 Organic Felt	8217.21	m2
3 mil Polyethylene	5216.28	m2
Aluminum	1.03	Tonnes
Ballast (aggregate stone)	1402665.01	kg
Batt. Fiberglass	29.73	m2 (25mm)
Batt. Rockwool	15148.11	m2 (25mm)
Concrete 20 MPa (flyash av)	1555.55	m3
Concrete 30 MPa (flyash av)	1076.41	m3
Concrete Blocks	139494.03	Blocks
EPDM membrane	554.14	kg
Galvanized Sheet	2.15	Tonnes
Mortar	444.21	m3
Nails	0.85	Tonnes
Polyethylene Filter Fabric	0.15	Tonnes
Rebar, Rod, Light Sections	321.38	Tonnes
Roofing Asphalt	13345.1	kg
Small Dimension Softwood Lumber, kiln-dried	28.73	m3
Stucco over porous surface	12195.26	m2
Water Based Latex Paint	1500.88	L
Welded Wire Mesh / Ladder Wire	0.96	Tonnes

Table 2: Bill of Materials

6.0 Summary Measures

The impact assessment portion of a LCA analyzes the impacts of the materials modeled for the chemistry building. The Impact Estimator delivers results of the manufacturing and construction stages of the Chemistry building. Results are further broken down into the impacts from materials and transportation within both phases. To be able to compare the results of the chemistry building to other buildings of varying sizes, the total impacts of both manufacturing and construction phases are divided by the square footage, to get a measurement of impact (ie. functional unit) that is comparable to other academic buildings.

The Impact Assessment results are divided into specific categories which give a general view of what the Chemistry building produces. An important measure for any environmental assessment is the amount of energy used. The primary energy consumption gives a value for this. The category of weighted resources use, quantifies the actual amount of materials used. Global warming potential, GWP, is a measure of all resulting outputs that have an adverse effect on the climate. The standard for GWP is in the base units of kg of CO2 equivalent. Acidification potential is a measure of the moles of hydrogen that are created from the materials and processes from the Chemistry building. HH respiratory effects potential, is the amount of particulate matter which has the potential to effect human health. Eutrophication potential is the increase of nutrients in bodies of water, which increases bacteria grow, therefore reducing fish and animal populations. Another important aspect of environmental assessment is the measure of ozone depleting chemicals. The Impact Estimator quantifies this by using the base units of kg of CFC-11 equivalent. Lastly the potential for smog to be created by the construction and manufacturing stages of the Chemistry building is given by the amount of Nitrogen Oxide equivalent. The results from each of these categories are listed below.

	Manufacturing			Construction			Total Effects	Total/ ft^2
	Material	Transportat	**Total**	Material	Transportat	**Total**		
Primary Energy Consumption MJ	1.50E+07	3.23E+05	1.53E+07	5.29E+05	1.05E+06	1.58E+06	**1.69E+07**	**2.15E+02**
Weighted Resource Use kg	8.38E+06	2.16E+02	8.38E+06	1.23E+04	6.93E+02	1.30E+04	**8.40E+06**	**1.07E+02**
Global Warming Potential (kg CO2 eq)	1.35E+06	5.78E+02	1.35E+06	3.58E+04	1.95E+03	3.77E+04	**1.39E+06**	**1.77E+01**
Acidification Potential (moles of H+ eq)	5.75E+05	1.95E+02	5.75E+05	1.87E+04	6.18E+02	1.93E+04	**5.95E+05**	**7.58E+00**
HH Respiratory Effects Potential (kg PM2.5	4.41E+03	2.35E-01	4.41E+03	2.11E+01	7.43E-01	2.19E+01	**4.44E+03**	**5.65E-02**
Eutrophication Potential (kg N eq)	6.93E+02	2.03E-01	6.93E+02	1.86E+01	6.40E-01	1.93E+01	**7.12E+02**	**9.08E-03**
Ozone Depletion Potential (kg CFC-11 eq)	2.87E-03	2.38E-08	2.87E-03	0.00E+00	7.98E-08	7.98E-08	**2.87E-03**	**3.65E-08**

Table 3: Summary Measures

The summary measures supplied from the impact estimators results will allow a quantifiable comparison to be made between buildings on the UBC campus and beyond. Since the results are based from one specific database uncertainties should be considered. Uncertainties in impact assessments can originate from data uncertainty, temporal variability and spatial variability. Data uncertainty can be the product of variances in the lifetime of chemicals and substances. The same substance can have a varying lifespan, which would differ the time period for which the effects of the chemical are felt. Temporal variability can vary results based on the amount of time for which a chemical is released, for instance an equivalent amount of nitrogen will have a different effect on a water body whether it is released for 3 weeks of 3 years. Lastly the spatial variability caused by regional differences creates uncertainty. Substances do not effect all areas of the world the same. Releasing pollutants into a stream rather than a large river will vary the effects on the environment.

6.1Sensitivity Analysis

A sensitivity analysis was performed for the Chemistry building by selecting the five materials with the greatest quantities and observing the effect of adding an extra 10 percent to each material individually. The change in all the categories, such as global warming potential, is then calculated. From this it can be determined which material has the greatest effect on the environment. During the design or renovation stage, this will help make decisions on which materials could possibly be switched for alternatives to mitigate certain environmental effects.

The sensitivity analysis for the ballast, which was a surrogate to model the exterior stone cladding, shows that their was a minimal change to any of the categories by adding 10%. Using more ballast in new buildings or the renovation of old buildings would be a beneficial option.

Impact Category	Units	Difference	% Difference
Primary Energy Consumption	MJ	4619.08	0.00
Weighted Resource Use	kg	34356.57	0.00
Global Warming Potential	(kg CO2 eq / kg)	151.46	0.00
Acidification Potential	(moles of H+ eq / kg)	41.88	0.00
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	53.21	0.01
Eutrophication Potential	(kg N eq / kg)	0.01	0.00
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0	0.00
Smog Potential	(kg NOx eq / kg)	0.14	0.00

Table 4: Ballast Sensitivity Analysis

The sensitivity analysis for concrete blocks shows a slight increase in a few of the categories in the summary measures. This seems to be appropriate since the manufacturing of concrete blocks is quite energy intensive, with many harmful outputs. The use of materials other than concrete block may be an appropriate alternative, for instance stone, as mentioned above.

Impact Category	Units	Difference	% Difference
Primary Energy Consumption	MJ	280037.46	0.02
Weighted Resource Use	kg	11692.65	0.00
Global Warming Potential	(kg CO2 eq / kg)	29810.86	0.02
Acidification Potential	(moles of H+ eq / kg)	12874.11	0.02
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	89.08	0.02
Eutrophication Potential	(kg N eq / kg)	5.79	0.01
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0	0.02
Smog Potential	(kg NOx eq / kg)	125.14	0.02

Table 5: Concrete Block Sensitivity Analysis

The analysis for concrete shows a substantial increase in weighted resource use, and a slight increase for all other categories. Concrete manufacturing and construction methods are quite energy intensive processes.

To mitigate environmental impacts it would be beneficial to explore other options such as wood, or steel.

Impact Category	Units	Difference	% Difference
Primary Energy Consumption	MJ	211563.06	0.01
Weighted Resource Use	kg	388334.73	0.05
Global Warming Potential	(kg CO2 eq / kg)	30237.56	0.02
Acidification Potential	(moles of H+ eq / kg)	11999.06	0.02
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	89.16	0.02
Eutrophication Potential	(kg N eq / kg)	7.21	0.01
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0	0.02
Smog Potential	(kg NOx eq / kg)	159.6	0.02

Table 6: Concrete 20 MPa Sensitivity Analysis

The sensitivity analysis for Rebar shows a large increase in the eutrophication potential as well as slight increases in most other categories. Certain alternatives could be chosen over the use of a concrete rebar system, for instance glulam beams or columns.

Impact Category	Units	Difference	% Difference
Primary Energy Consumption	MJ	559166.83	0.03
Weighted Resource Use	kg	46935.83	0.01
Global Warming Potential	(kg CO2 eq / kg)	18757.42	0.01
Acidification Potential	(moles of H+ eq / kg)	6302.5	0.01
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	35.34	0.01
Eutrophication Potential	(kg N eq / kg)	36.48	0.05
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0	0.00
Smog Potential	(kg NOx eq / kg)	15.65	0.00

Table 7: Rebar Sensitivity Analysis

The sensitivity analysis for roofing asphalt shows little to no change in any of the summary measure categories. Therefore, roofing asphalt might be a better option than other roofing materials.

Impact Category	Units	Difference	% Difference
Primary Energy Consumption	MJ	24316.3	0.00
Weighted Resource Use	kg	552.96	0.00
Global Warming Potential	(kg CO2 eq / kg)	1065.32	0.00
Acidification Potential	(moles of H+ eq / kg)	534.48	0.00
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	2.67	0.00
Eutrophication Potential	(kg N eq / kg)	0.18	0.00
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0	0.00
Smog Potential	(kg NOx eq / kg)	4.75	0.00

Table 8: Roofing Asphalt Sensitivity Analysis

7.0 Building Performance

The performance of an old building, such as UBC's Chemistry building, can be greatly improved by adding energy efficient components. To meet the insulation requirements, set by the Residential Environmental Assessment Program (REAP), roofs must have R-value of 40, walls must have an R-value of at least 18 and windows are required to have a R-value of 3.2. R-values represent the thermal resistance of a material, which is the difference of temperatures across an insulator.

To improve the Chemistry building's envelope performance a few things could be done. Firstly the walls should be insulated. The original plans specified that the exterior walls were made of brick with stone cladding and without any insulation. A solution could be to inject expanded polystyrene foam into any voids and behind any interior wall finishing. Another alternative could be to renovate all interior sides of the outside walls, to allow for other insulation to be placed as a layer. To improve the performance of the windows, the old single pained windows could be replaced with aluminum framed, low E, silver argon filled windows. These windows have a very high R-value, which could really help lower the heat loss. Finally to create a more energy efficient roof, polystyrene expanded foam could be injected into any spaces, such as attics or in between beams.

To determine what effects the improvements may have on the Chemistry building the original heat loss effects need to be calculated and compared to the improved heat loss performance. The following calculation is used to determine heat loss.

$$Q = (1/R) \times A \times \Delta T$$

Q being the annual heat loss calculated using R, which is the weighted R value of the entire building envelope; A, which is the entire building's surface area; and ΔT, which is the difference between the outside and inside temperatures, based on historical monthly values. The values for Q are then converted from BTU, to Joules. Next the new building envelope components are added into the Impact Estimator and a new summary measures table is outputted. The difference between the improved and the current primary energy consumption is calculated, and this is the initial invested embodied energy of the improvements. The heat loss of both the improved and current building envelope are compared and graphed to determine at what point will the building be saving energy compared to the initial investment, called the payback period.

From the graph, below, we can extract the payback period occurs at 3 years after the improvements are completed. This is a short time period that encourages the improvements to be made, based on this simple energy model. However, one must make other considerations when deciding whether or not to follow through with the envelope upgrade. Firstly renovations can be quite expensive and can create a lot of waste that may be completely discarded in landfills. If the current components that are to be replaced, are recyclable, then this would make the improvements a favorable option. Secondly environmental concerns should be thought through. In an old building such as the Chemistry building, materials such as asbestos may have been used. Renovating components consisting of asbestos can be a large financial undertaking, as well as an environmental concern if not renovated correctly. Lastly, the Chemistry building is in constant use to hold labs and lectures. To perform renovations would mean that classes and labs would have to be relocated. Other classes and labs would have to be used, which might require UBC to construct new facilities. These are all considerations that should be further investigated to determine if the building envelope upgrade is feasible. Just purely based on this energy model, it seems that the building envelope improvements would be beneficial; further study should be done to confirm this, considering all other finical, environmental and logistical concerns

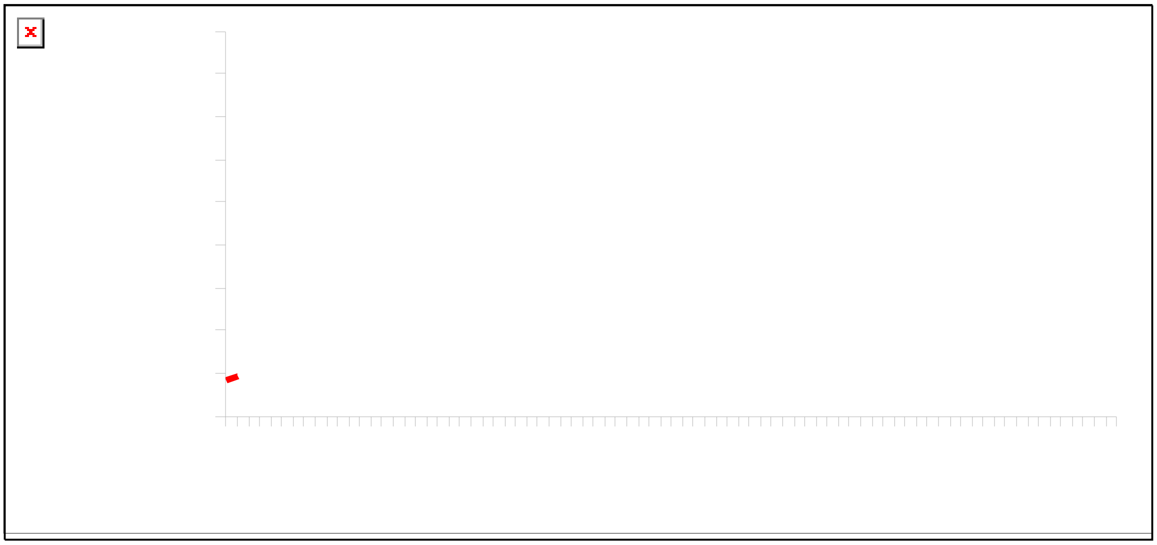

Illustration 1: Energy Payback Graph

8.0 Conclusion

To develop a life cycle assessment for the Chemistry building, the quantities of materials required to construct the structure where required to be modeled. From modeling the Chemistry building at UBC, the five largest quantities of materials were discovered to be ballast, concrete blocks, 20 MPa cement, rebar and roofing asphalt. By adding an extra 10 percent of each of these materials individually, their specific environmental impacts were evaluated. It was discovered that concrete and rebar create a substantial increase in the summary measure categories. Alternatives of the concrete rebar system should be evaluated. The evaluation however requires that all aspect be considered, such as the fact that the concrete rebar construction system is so versatile since its completely form-able on sight. The performance of the Chemistry building's envelope was also modeled to determine if improvements to windows and insulation should be completed. It was discovered that to have a return on the initial energy investment for the renovation, it would only take 3 years. This seems to be enough reason to make the improvements, but other issues should be considered. Considerations that should be evaluated in greater detail include the economic feasibility of the renovations, the environmental impacts of waste materials created and the logistics of relocating students to other class and lab facilities. These further studies could be completed as well as expanding the scope of the LCA to maintenance, end of life and operating phases to gain a better understanding of the Chemistry building and decisions related to it.

Appendix A:

Chemistry Building IE Input Document

Assembly Group	Assembly Type	Assembly Name	Input Fields	Input Values	
				Known/Measured	IE Inputs
1 Foundation					
	1.1 Concrete Slab-on-Grade				
		1.1.1 SOG_Basement			
			Length (ft)	108.94	108.94
			Width (ft)	108.94	108.94
			Thickness (in)	6	4
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
	1.2 Concrete Footing				
		1.2.1 Footing_Thickness 2'			
			Length (ft)	22.58	25.38
			Width (ft)	22.58	25.38
			Thickness (in)	24	0
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#6	#6
		1.2.2 Footing_Thickness 2' 6”			
			Length (ft)	45.35	56.99
			Width (ft)	45.35	56.99
			Thickness (in)	30	0
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#6	#6
		1.2.3. Footing_Thickness 3'			
			Length (ft)	11.27	15.51
			Width (ft)	11.27	15.51
			Thickness (in)	36	19
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#6	#6
		1.2.4 Footing_Thickness 3'6”			
			Length (ft)	22.96	34.13
			Width (ft)	22.96	34.13

			Thickness (in)	42	19
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#6	#6
	1.3 Concrete Stairs				
		1.3.1 Stairs_Thickness 7”			
			Length (ft)	39.65	39.65
			Width (ft)	39.65	39.65
			Thickness (in)	7	7
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#4
		1.3.2 Stairs_Thickness 11”			
			Length (ft)	10.29	10.29
			Width (ft)	10.29	10.29
			Thickness (in)	11	11
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#6	#6
2 Walls	2.1 Cast In Place				
		2.1.1 Walls_Foundation Trench 3'3"			
			Length (ft)	67	67.00
			Height (ft)	3.25	3.25
			Thickness (in)	8	8
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.1.2 Walls_Foundation Elevator 3'6"			
			Length (ft)	31	31
			Height (ft)	3.5	3.5
			Thickness (in)	8	8
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.1.3 Walls_Foundation South 13'			
			Length (ft)	127	127
			Height (ft)	13	13
			Thickness (in)	8	8
			Concrete (psi)	3000	3000

		Concrete flyash %	-	average
		Rebar	#4	#5
	Envelope	Category	Vapour Barrier	Vapour Barrier
		Material	Polyethylene 3 mil	Polyethylene 3 mil
		Thickness	-	-
	2.1.4 Walls_Foundation South:2 14'4"			
		Length (ft)	342	342
		Height (ft)	14.33	14.33
		Thickness (in)	8	8
		Concrete (psi)	3000	3000
		Concrete flyash %	-	average
		Rebar	#4	#5
	Envelope	Category	Vapour Barrier	Vapour Barrier
		Material	Polyethylene 3 mil	Polyethylene 3 mil
		Thickness	-	-
	2.1.5 Walls_Foundation West 13'6"			
		Length (ft)	307	307
		Height (ft)	13.5	13.5
		Thickness (in)	8	8
		Concrete (psi)	3000	3000
		Concrete flyash %	-	average
		Rebar	#4	#5
	Envelope	Category	Vapour Barrier	Vapour Barrier
		Material	Polyethylene 3 mil	Polyethylene 3 mil
		Thickness	-	-
	2.1.6 Walls_Foundation West:2 11'			
		Length (ft)	77	77.00
		Height (ft)	11	11
		Thickness (in)	8	8
		Concrete (psi)	3000	3000
		Concrete flyash %	-	average
		Rebar	#4	#5
	Envelope	Category	Vapour Barrier	Vapour Barrier
		Material	Polyethylene 3 mil	Polyethylene 3 mil
		Thickness	-	-
	2.1.7 Walls_Foundation North 10'			
		Length (ft)	28	28
		Height (ft)	10	10
		Thickness (in)	8	8
		Concrete (psi)	3000	3000
		Concrete flyash %	-	average
		Rebar	#4	#5
	Envelope	Category	Vapour Barrier	Vapour Barrier
		Material	Polyethylene 3 mil	Polyethylene 3 mil

			Thickness	-	-
		2.1.8 Walls_Foundation North:2 6'			
			Length (ft)	28	37.33
			Height (ft)	6	6
			Thickness (in)	16	12
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.1.7 Walls_Foundation Southeast Wing 3'6"			
			Length (ft)	212	212
			Height (ft)	3.5	3.5
			Thickness (in)	8	8
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.1.8 Walls_Foundation Trench 1'9"			
			Length (ft)	125	125.00
			Height (ft)	1.75	1.75
			Thickness (in)	8	8
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.1.8 Walls_Basement Exterior 3			
			Length (ft)	119	119.00
			Height (ft)	11.33	11.33
			Thickness (in)	8	8
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
	2.2 Concrete Block Wall				
		2.2.1 Walls_Basement Exterior 1			

			Length (ft)	677	677
			Height (ft)	11.33	11.33
			Rebar	#4	#4
		Window Opening	Number of Windows	38	38
			Total Window Area (ft2)	785	785
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	None
		Door Opening	Number of Doors	6	6
			Door Type	-	Solid Wood
		Envelope	Category	Cladding	Cladding
			Material	Stone	Aggregate (XBM 6.1)
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Plaster	Stucco on porous surface
			Thickness	-	-
			Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.2.2 Walls_Basement Exterior 2			
			Length (ft)	40	80
			Height (ft)	11.33	11.33
			Rebar	#4	#4
		Window Opening	Number of Windows	2	2
			Total Window Area (ft2)	48	48
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	None
		Envelope	Category	Cladding	Cladding
			Material	Stone	Aggregate (XBM 6.1)
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Plaster	Stucco on porous surface
			Thickness	-	-
			Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 3 mil	Polyethylene 3 mil
			Thickness	-	-
		2.2.3 Walls_Basement Interior 1			
			Length (ft)	535	535
			Height (ft)	11.33	11.33
			Rebar	#4	#4
		Door Opening	Number of Doors	25	25
			Door Type	-	Solid Wood
		Envelope	Category	Cladding	Cladding

	Material	Plaster	Stucco on porous surface
	Thickness	-	-
2.2.4 Walls_Basement Interior 2			
	Length (ft)	1268	951
	Height (ft)	11.33	11.33
	Rebar	#4	#4
Door Opening	Number of Doors	24	24
	Door Type	-	Solid Wood
Envelope	Category	Cladding	Cladding
	Material	Plaster	Stucco on porous surface
	Thickness	-	-
2.2.5 Walls_1st: Exterior 1			
	Length (ft)	806	806
	Height (ft)	13.167	13.167
	Rebar	#4	#4
Window Opening	Number of Windows	50	50
	Total Window Area (ft2)	2148	2148
	Frame Type	Wood Frame	Wood Frame
	Glazing Type	-	None
Door Opening	Number of Doors	4	4
	Door Type	-	Solid Wood
Envelope	Category	Cladding	Cladding
	Material	Stone	Aggregate (XBM 6.1)
	Thickness	-	-
	Category	Cladding	Cladding
	Material	Plaster	Stucco on porous surface
	Thickness	-	-
2.2.6 Walls_1st: Exterior 2			
	Length (ft)	38	76
	Height (ft)	13.167	13.167
	Rebar	#4	#4
Window Opening	Number of Windows	2	2
	Total Window Area (ft2)	88	88
	Frame Type	Wood Frame	Wood Frame
	Glazing Type	-	None
Envelope	Category	Cladding	Cladding
	Material	Stone	Aggregate (XBM 6.1)
	Thickness	-	-
	Category	Cladding	Cladding
	Material	Plaster	Stucco on porous surface
	Thickness	-	-
2.2.7 Walls_1st: Interior 1			

		Length (ft)	418	418
		Height (ft)	13.02	13.02
		Rebar	#4	#4
	Door Opening	Number of Doors	17	17
		Door Type	-	Solid Wood
		Category	Cladding	Cladding
		Material	Plaster	Stucco on porous surface
		Thickness	-	-
2.2.8 Walls_1st: Interior 2				
		Length (ft)	1294	971
		Height (ft)	13.167	13.167
		Rebar	#4	#4
	Door Opening	Number of Doors	28	28
		Door Type	-	Solid Wood
	Envelope	Category	Gypsum Board	Gypsum Board
		Material	Gypsum Regular 1/2”	Gypsum Regular ½"
		Thickness	-	-
2.2.9 Walls_2nd: Exterior 1				
		Length (ft)	775	775
		Height (ft)	13.167	13.167
		Rebar	#4	#4
	Window Opening	Number of Windows	60	60
		Total Window Area (ft2)	2213	2213
		Frame Type	Wood Frame	Wood Frame
		Glazing Type	-	None
	Envelope	Category	Cladding	Cladding
		Material	Stone	Aggregate (XBM 6.1)
		Thickness	-	-
		Category	Cladding	Cladding
		Material	Plaster	Stucco on porous surface
		Thickness	-	-
2.2.10 Walls_2nd: Exterior 2				
		Length (ft)	40	80
		Height (ft)	13.167	13.167
		Rebar	#4	#4
	Window Opening	Number of Windows	2	2
		Total Window Area (ft2)	86	86
		Frame Type	Wood Frame	Wood Frame
		Glazing Type	-	None
	Envelope	Category	Cladding	Cladding
		Material	Stone	Aggregate (XBM 6.1)
		Thickness	-	-
		Category	Cladding	Cladding

		Material	Plaster	Stucco on porous surface
		Thickness	-	-
	2.2.11 Walls_2nd: Interior 1			
		Length (ft)	543	543
		Height (ft)	13.167	13.167
		Rebar	#4	#4
	Door Opening	Number of Doors	15	15
		Door Type	-	Solid Wood
	Envelope	Category	Cladding	Cladding
		Material	Plaster	Stucco on porous surface
		Thickness	-	-
	2.2.12 Walls_2nd: Interior 2			
		Length (ft)	1222	917
		Height (ft)	13.167	13.167
		Rebar	#4	#4
	Door Opening	Number of Doors	26	26
		Door Type	-	Solid Wood
	Envelope	Category	Cladding	Cladding
		Material	Plaster	Stucco on porous surface
		Thickness	-	-
	2.2.13 Walls_3rd: Exterior 1			
		Length (ft)	799	799
		Height (ft)	21	21
		Rebar	#4	#4
	Window Opening	Number of Windows	33	33
		Total Window Area (ft2)	988	988
		Frame Type	Wood Frame	Wood Frame
		Glazing Type	-	None
	Envelope	Category	Cladding	Cladding
		Material	Stone	Aggregate (XBM 6.1)
		Thickness	-	-
		Category	Cladding	Cladding
		Material	Plaster	Stucco on porous surface
		Thickness	-	-
	2.2.14 Walls_3rd: Exterior 2			
		Length (ft)	33	66
		Height (ft)	21	21
		Rebar	#4	#4
	Window Opening	Number of Windows	2	2
		Total Window Area (ft2)	84	84
		Frame Type	Wood Frame	Wood Frame
		Glazing Type	-	None
	Envelope	Category	Cladding	Cladding

			Material	Stone	Aggregate (XBM 6.1)
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Plaster	Stucco on porous surface
			Thickness	-	-
		2.2.15 Walls_3rd: Interior 1			
			Length (ft)	606	606
			Height (ft)	13.167	13.167
			Rebar	#4	#4
		Door Opening	Number of Doors	24	24oc
			Door Type	-	Solid Wood
		Envelope	Category	Cladding	Cladding
			Material	Plaster	Stucco on porous surface
			Thickness	-	-
		2.2.16 Walls_3rd: Interior 2			
			Length (ft)	1262	946
			Height (ft)	13.167	13.167
			Rebar	#4	#4
		Door Opening	Number of Doors	22	22
			Door Type	-	Solid Wood
		Envelope	Category	Cladding	Cladding
			Material	Plaster	Stucco on porous surface
			Thickness	-	-
		2.2.17 Walls_Penthouse: Exterior 1			
			Length (ft)	338	338
			Height (ft)	10.67	10.67
			Rebar	#4	#4
		Window Opening	Number of Windows	10	10
			Total Window Area (ft2)	187	187
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	None
		Envelope	Category	Cladding	Cladding
			Material	Stone	Aggregate (XBM 6.1)
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Plaster	Stucco on porous surface
			Thickness	-	-
3 Columns and Beams	3.1 Concrete Column and Beam Basement				
		3.1.1 Column_Beams_Basement: 1			
			Number of Beams	27	27

			Number of Columns	46	46
			Floor to floor height (ft)	6.83	6.83
			Bay sizes (ft)	26.67	26.67
			Supported span (ft)	13.08	13.08
			Live load (psf)	-	75
		3.1.2 Column_Beams_Basement: 2			
			Number of Beams	2	2
			Number of Columns	4	4
			Floor to floor height (ft)	6.83	6.83
			Bay sizes (ft)	32.5	32.5
			Supported span (ft)	16	16
			Live load (psf)	-	75
		3.1.3 Column_Beams_Basement: 3			
			Number of Beams	2	2
			Number of Columns	2	2
			Floor to floor height (ft)	6.83	6.83
			Bay sizes (ft)	12.17	12.17
			Supported span (ft)	16	16
			Live load (psf)	-	75
	3.2 Concrete Column and Beams 1st/2nd/3rd Floors				
		3.2.1 Column_Beams_1st/2nd/3rd: 1			
			Number of Beams	113	113
			Number of Columns	197	197
			Floor to floor height (ft)	13.17	13.17
			Bay sizes (ft)	26.67	26.67
			Supported span (ft)	13.08	13.08
			Live load (psf)	-	75
		3.2.2 Column_Beams_1st/2nd/3rd: 2			
			Number of Beams	6	6
			Number of Columns	12	12
			Floor to floor height (ft)	13.17	13.17
			Bay sizes (ft)	32.5	32.5
			Supported span (ft)	16	16
			Live load (psf)	-	75
		3.2.3 Column_Beams_1st/2nd/3rd: 3			
			Number of Beams	6	6

			Number of Columns	6	6
			Floor to floor height (ft)	13.17	13.17
			Bay sizes (ft)	12.17	12.17
			Supported span (ft)	16	16
			Live load (psf)	-	75
	3.3 Concrete Column and Beams Roof				
		3.2.1 Column_Beams_Roof: 1			
			Number of Beams	40	40
			Number of Columns	66	66
			Floor to floor height (ft)	21	21
			Bay sizes (ft)	26.67	26.67
			Supported span (ft)	13.08	13.08
			Live load (psf)	-	75
		3.2.2 Column_Beams_Roof: 2			
			Number of Beams	2	2
			Number of Columns	4	4
			Floor to floor height (ft)	21	21
			Bay sizes (ft)	32.5	32.5
			Supported span (ft)	16	16
			Live load (psf)	-	75
		3.2.3 Column_Beams_Roof: 3			
			Number of Beams	2	2
			Number of Columns	2	2
			Floor to floor height (ft)	21	21
			Bay sizes (ft)	12.17	12.17
			Supported span (ft)	16	16
			Live load (psf)	-	75
	3.4 Concrete Column and Beams Penthouse				
		3.4.1 Column_Beams_Penthouse: 1			
			Number of Beams	4	4
			Number of Columns	6	6
			Floor to floor height (ft)	10.67	10.67
			Bay sizes (ft)	12.17	12.17
			Supported span (ft)	15.83	15.3
			Live load (psf)	-	75
4 Floors	4.2 Concrete Suspended Slab 6”				
		4.1.1 Floors_Basement/1st/2nd/3rd			
			Floor Width (ft)	4618.9	4618.9
			Span (ft)	13.08	13.08

			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Life load (psf)	-	75
	4.2 Concrete Suspended Slab 10”				
		4.2.1 Floors_1st/2nd			
			Floor Width (ft)	123.1	123.1
			Span (ft)	16	16
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Life load (psf)	-	75
5 Roof	5.1 Concrete Suspended Slab				
		5.1.1 Roof			
			Roof Width (ft)	1482.9	1482.9
			Span (ft)	13.08	13.08
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Life load (psf)	-	75
		Envelope	Category Material Thickness(inches)	4ply Built up Asphalt Roof System – inverted Rockwool glass felt -	4ply Built up Asphalt Roof System – inverted Rockwool glass felt 8
			Category Material	Vapour Barrier -	Vapour Barrier Polyethylene 3 mil
6 Extra Basic Materials	6.1 Stone Cladding				
		6.1.1 XBM_Stone Ballast			
			Weight (lbs)	2 706 734.2	999 999.01

Appendix B:

Chemistry Building IE Input Assumptions Document

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Foundation	The Impact Estimator, SOG inputs are limited to being either a 4" or 8" thickness. Since the actual SOG thicknesses for the Chemistry building were not exactly 4" or 8" thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. The Impact Estimator limits the thickness of footings to be between 7.5" and 19.7" thick. As there are a number of cases where footing thicknesses exceed 19", their widths were increased accordingly to maintain the same volume of footing while accommodating this limitation. Lastly, the concrete stairs were modelled as footings (ie. Stairs_Concrete_TotalLength).		
	1.1 Concrete Slab-on-Grade		
		1.1.1 SOG_Basement	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[(17802 x (6"/12))/(4"/12)] = 108.94 ft Assume 3 mil polyethylene vapour barrier Assume concrete 3000 psi
	1.2 Concrete Footing		

		1.2.1 Footing_Thickness 2'	The area of this footing slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The thicknesses were set at 19” and the following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Footing Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(510 x (24”/12))/(19”/12)] = 25.38 ft Assume no vapour barrier Assume concrete 4000 psi
		1.2.2 Footing_Thickness 2'6”	The area of this footing slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The thicknesses were set at 19” and the following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Footing Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(2057 x (30”/12))/(19”/12)] = 56.99 ft Assume no vapour barrier Assume concrete 4000 psi
		1.2.3 Footing_Thickness 3'	The area of this footing slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The thicknesses were set at 19” and the following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Footing Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(127 x (36”/12))/(19”/12)] = 15.51 ft Assume no vapour barrier Assume concrete 4000 psi

		1.2.4 Footing_Thickness 3'6"	The area of this footing slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7". The thicknesses were set at 19" and the following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Footing Slab Area) x (Actual Slab Thickness))/(4"/12)] = sqrt[(527 x (42"/12))/(19"/12)] = 34.13 ft Assume no vapour barrier Assume concrete 4000 psi
	1.3 Concrete Stairs		
		1.3.1 Stairs_Thickness 7"	The thickness of the stairs was estimated to be 7 inches based on the cross-section structural drawings. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Concrete Stair Volume) / (Slab Thickness/12)] = sqrt[917 /(7"/12)] = 39.65 ft Assume concrete 3000 psi
		1.3.2 Stairs_Thickness 11"	The thickness of the stairs was estimated to be 11 inches based on the cross-section structural drawings. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Concrete Stair Volume) / (Slab Thickness/12)] = sqrt[97 /(11"/12)] = 10.29 ft Assume concrete 3000 psi
2 Walls			
	2.1 Cast In Place		

		2.1.1 Wall_Foundation Trench 3'3"	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.2 Walls_Foundation Elevator 3'6"	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.3 Walls_Foundation South 13'	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.4 Walls_Foundation South:2 14'4"	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.5 Walls_Foundation West 13'6"	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.6 Walls_Foundation West:2 11'	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.7 Walls_Foundation North 10'	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.8 Walls_Foundation North:2 6'	This wall was increased by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (28") * [(16”)/12”] = 37.33 feet Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.5 Walls_Foundation Southeast Wing 3'6"	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier

		2.1.6 Walls_Foundation Trench 1'9"	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier
		2.1.6 Walls_Basement Exterior 3	Assume concrete 3000 psi Assume 3 mil polyethylene vapour barrier Assume rebar #4 Assume plaster on interior walls. Use stucco on porous surface as surrogate
	2.2 Concrete Block Wall		
		2.2.1 Walls_Basement Exterior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood, fixed, windows with no glazing Assume solid wood doors Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume 3 mil polyethylene vapour barrier Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.2 Walls_Basement Exterior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the wall width is 16” use twice the length of block wall; = (Wall length(ft)) * (Width/8”) =(40) * (16/8) = 80 ft Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume 3 mil polyethylene vapour barrier Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.3 Walls_Basement Interior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.4 Walls_Basement Interior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the width of the wall is not 8” the following calculation was done in order to determine appropriate Length (in feet) inputs the wall; = (Wall length(ft)) * (Width/8”) =(1268) * (6/8) = 951 ft Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.5 Walls_1st: Exterior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood, fixed, windows with no glazing Assume solid wood doors Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.6 Walls_1st: Exterior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the wall width is 16” use twice the length of block wall; = (Wall length(ft)) * (Width/8”) =(38) * (16/8) = 76 ft Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.7 Walls_1st: Interior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.8 Walls_1st: Interior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the width of the wall is not 8” the following calculation was done in order to determine appropriate Length (in feet) inputs the wall; = (Wall length(ft)) * (Width/8”) =(1294) * (6/8) = 971 ft Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.9 Walls_2nd: Exterior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.10 Walls_2nd: Exterior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the wall width is 16” use twice the length of block wall; = (Wall length(ft)) * (Width/8”) =(40) * (16/8) = 80 ft Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.11 Walls_2nd: Interior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.12 Walls_2nd: Interior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the width of the wall is not 8” the following calculation was done in order to determine appropriate Length (in feet) inputs the wall; = (Wall length(ft)) * (Width/8”) =(1222) * (6/8) = 917 ft Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.13 Walls_3rd: Exterior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Wall Height: Slab top to slab bottom + 7'8” for attic walls and decorative on the perimeter of the roof. Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.14 Walls_3rd: Exterior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the wall width is 16” use twice the length of block wall; = (Wall length(ft)) * (Width/8”) =(33) * (16/8) = 66 ft Wall Height: Slab top to slab bottom + 7'8” for attic walls and decorative on the perimeter of the roof. Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.15 Walls_3rd: Interior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate

		2.2.16 Walls_3rd: Interior 2	Assume concrete block for brick walls. The standard width of a concrete block is 8”. Since the width of the wall is not 8” the following calculation was done in order to determine appropriate Length (in feet) inputs the wall; = (Wall length(ft)) * (Width/8”) =(1262) * (6/8) = 946 ft Assume rebar #4 Assume solid wood doors Assume no interior windows since not specified on plans Assume plaster on interior walls. Use stucco on porous surface as surrogate
		2.2.17 Walls_Penthouse: Exterior 1	Assume concrete block for brick walls. The standard width of a concrete block is 8”. This corresponds to the measured wall width. Assume rebar #4 Assume solid wood, fixed, windows with no glazing Stone cladding will be added as aggregate in the Extra Basic Materials section 6.1 Assume plaster on interior walls. Use stucco on porous surface as surrogate
3 Columns and Beams	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. Since the live loading was not located within the provided building information, a live load of 75psf on all four floors and the basement level were assumed.		
	3.1 Concrete Column and Beams Basement		
		3.1.1 Column_Beams_Basement: 1	Assume live loading to be 75 psf Some beams that are slightly larger and smaller where incorporated into this count
		3.1.2 Column_Beams_Basement: 2	Assume live loading to be 75 psf
		3.1.3 Column_Beams_Basement: 3	Assume live loading to be 75 psf
	3.2 Concrete Column and Beams 1st/2nd/3rd Floors		

		3.2.1 Column_Beams_1st/2nd/3rd: 1	Assume live loading to be 75 psf Some beams that are slightly larger and smaller where incorporated into this count
		3.2.2 Column_Beams_1st/2nd/3rd: 2	Assume live loading to be 75 psf
		3.2.3 Column_Beams_1st/2nd/3rd: 2	Assume live loading to be 75 psf
	3.3 Concrete Column and Beams Roof		
		3.3.1 Column_Beams_Roof: 1	Assume live loading to be 75 psf Some beams that are slightly larger and smaller where incorporated into this count
		3.3.2 Column_Beams_Roof: 2	Assume live loading to be 75 psf
		3.3.3 Column_Beams_Roof: 3	Assume live loading to be 75 psf
	3.4 Concrete Column and Beams Penthouse		
		3.4.1 Column_Beams_Penthouse: 1	Assume live loading to be 75 psf
4 Floors	The Impact Estimator calculated the thickness of the material based on floor width, span, concrete strength, concrete flyash content and live load. The only assumptions that had to be made in this assembly group were setting the live load to 75psf, as well as setting the concrete strength 3,000 and fly ash to average.		
	4.1 Concrete Suspended Slab 6”		
		4.1.1 Floors_Basement/1st/2nd/3rd	To enter the area of the floors in to the Impact Estimator the width and span need to be designated. The following calculation was done to determine the total width (in feet) for all floors from the measured area. The smaller range of the span size, 13.08 ft, was used in the calculation: = (Sum of all floor areas) / (Span size) =(60415) / (13.08) =4618.9 ft Assume concrete 3000 psi Assume live loading to be 75 psf Assume average fly ash Assume no envelope
	4.2 Concrete Suspended Slab 10”		

		4.2.1 Floors_1st/2nd	To enter the area of the floors in to the Impact Estimator the width and span need to be designated. The following calculation was done to determine the total width (in feet) for all floors from the measured area. The larger range of the span size, 16 ft, was used in the calculation to get a thicker slab that more closely represents the 10" thickness: = (Sum of all floor areas) / (Span size) =(1969) / (16) =123.1 ft Assume concrete 3000 psi Assume live loading to be 75 psf Assume average fly ash Assume no envelope
5 Roof	The live load was assumed to be 75 psf and the concrete strength was set to3000psi.		
	5.1 Concrete Suspended Slab		
		5.1.1 Roof	To enter the area of the roof in to the Impact Estimator the width and span need to be designated. The following calculation was done to determine the total width (in feet) for all roofs from the measured area. The smaller range of the span size, 13.08 ft, was used in the calculation: = (Sum of all floor areas) / (Span size) =(19396) / (13.08) =1482.9 ft Assume 4 ply Built up Asphalt Roof System – inverted, with Rockwool glass felt at a thickness of 8". Assume 3 mil polyethylene vapour barrier
6 Extra Basic Materials	To model the stone cladding on all the exterior wall, ballast, or stone aggregate, will be used as a surrogate The surface area of each exterior will be multiplied by the thickness and then multiplied by the density to determine the mass of stone required.		
	6.1 Stone Cladding		
		6.1.1 XBM_Stone Ballast	

			Assume that ballast is an appropriate approximation of exterior stone cladding. Assume density of stone to be 2515 (kg/m^3) * 0.0624 = 156.9 (lbs/ft^3) *http://www.simetric.co.uk/si_materials.htm Total weight calculations: =(Exterior Surface Area(ft^2)) * (Cladding Thickness(ft)) * (Density(lbs/ft^3)) =(51754) * (4”/12) * (156.9) =2 706 734.2 lbs Impact Estimator only allows ballast material only to be up to 6 digits so 902244.7 was add separately in the estimator, then the summary measures were multiplied by 3 and added to the original summary table.