LIFE CYCLE ANALYSIS OF THE H.R. MACMILLAN BUILDING, UNIVERSITY OF BRITISH COLUMBIA

Ivan Yip-Hang Tang
CIVL 498C, University of British Columbia
March 30, 2009

ABSTRACT

A life cycle analysis of the materials used for the structural and envelope elements was completed for the H.R. MacMillan building at the University of British Columbia (UBC). This study, completed in conjunction with twelve other studies on UBC buildings, was done to determine the environmental impacts of the building design and its construction elements. The scope of this LCA study covers the structure, envelope and operational energy usage of the H.R. MacMillan building on a square foot basis.

OnCenter's OnScreen Takeoff and the Athena Sustainable Materials Institute's Impact Estimator (IE) were the two main software tools used. OnScreen Takeoff was first used to create an inventory of the construction elements in the building. That data was then formatted and entered into the Impact Estimator, from which reports can be generated to show measures based on the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2, developed by the US Environmental Protection Agency (US EPA). The environmental impacts of the building are quantified in eight TRACI impact categories, such as primary energy consumption and global warming potential. In both performing the takeoffs and creating the building model in IE, a number of assumptions had to be made, adding uncertainties to the results. For this LCA, only the manufacturing and construction life cycle stages are considered.

Highlights of the results include: 437 MJ of embodied energy per square foot, 250 kg of weighted raw resource use per square foot, and less than 0.01 kg CFC-11 equivalent/kg ozone depletion potential per square foot. It was concluded that the H.R. MacMillan building has a higher environmental impact that the average academic building. A sensitivity analysis was completed to analyze the relative effects of five materials. Concrete and bricks had by far the largest effects in each of the impact categories. An analysis was also completed to assess the energy performance of the building. The current insulation of the building was compared to improved insulation to meet the Residential Environmental Assessment Program (REAP) standards. The payback period of the building with the improved insulation was found to be less than three years.

TABLE OF CONTENTS

Appendix A – Formatted Inputs

Appendix B – Input Assumptions

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The H.R. MacMillan building, originally the Forestry Agriculture building, was built in 1967 on the Point Grey campus of the University of British Columbia. The design of the concrete and brick building was of 'Modern Tudor' architecture, featuring Gothic-style ornaments and brick pilasters. It has a unique shape, enclosing a semi-vegetated courtyard containing several trees (see **Figure 1**). The three-storey-plus-one-ground-floor building serves as an academic research building, originally containing approximately 11 classrooms, 43 labs and 65 offices. It also features one large lecture theatre, and a library on the top floor. **Table 1** details the building's structural and envelope elements. The building is heated by steam provided from a centralized generator on campus burning natural gas.

Figure 1 - Aerial View of the H.R. MacMillan Building

Table 1 - Building Characteristics

Building System	Specific characteristics of MacMillan
Structure	Concrete beams and columns, and concrete blocks supporting concrete tees; Penthouse: steel WF beams and columns
Floors	Ground: Concrete slab on grade with polyethylene vapour barrier; First, Second, and Third Floors: Concrete tees with topping
Exterior Walls	Ground: Cast in place walls, some with modular brick cladding, rigid insulation; First, Second, and Third Floors: concrete block walls with modular brick cladding, rigid insulation and windows, concrete cast in place walls with modular brick cladding and rigid insulation; Penthouse: modular brick cladding
Interior Walls	Ground: concrete block walls; First, Second, and Third Floors: concrete block walls, some with plaster or modular brick cladding, and aluminum framed curtain walls
Windows	Most windows standard single glazed, either aluminum or steel frames, a few windows double glazed
Roof	Main Roof: Suspended slab with rigid insulation, some with plaster; Penthouse Roof: Steel decking

GOAL AND SCOPE

The goal and scope of this study, as discussed in the subsequent sections, was defined in accordance to International Standard ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

Goal of Study

This life cycle analysis (LCA) of the H.R. MacMillan building (hereafter referred to as MacMillan) at the University of British Columbia (UBC) was carried out as an exploratory study to determine the environmental impact of its design. This LCA of MacMillan 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 H.R. MacMillan building. An exemplary application of these references is in the assessment of potential future performance upgrades to the structure and envelope of MacMillan. 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 MacMillan 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.

Scope of Study

The product system studied in this LCA are the structure, envelope and operational energy usage associated with space conditioning of MacMillan 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 MacMillan, as well as associated transportation effects throughout.

Tools, Methodology and Data

There were two main software tools utilized to complete this LCA study; OnCenter's OnScreen Takeoff and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings.

The initial stage of the study was a materials quantity takeoff, which involved performing linear, area and count measurements of the building's structure and envelope. To accomplish this, OnScreen Takeoff version 3.6.2.25 was 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 4.0.51 of the IE software, the only available software capable of meeting the requirements of this study, was used to generate a whole building LCA model for MacMillan 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 into the initial structure and envelope assemblies. As this study is a cradle-to-gate assessment, the expected service life of

MacMillan 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 MacMillan, all of the available TRACI impact assessment categories available in the IE are included in this study, and are listed as;

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

Using the summary measure results, a sensitivity analysis was then conducted in order to reveal the effect of material changes on the impact profile of MacMillan. 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 H.R. MacMillan building was initially constructed in 1967. The assemblies of the building that were modelled include the foundation, columns and beams, floors, walls and roofs, as well as the associated envelope and openings (i.e. doors and windows) within each of these assemblies. The decision to omit other building components, such as flooring, electrical aspects, heating, ventilation and air conditioning (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 modelling 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 limitations will be discussed further in the Building Model section and, as previously mentioned, all specific input related assumptions are contained in the **Input Assumptions** document in **Appendix B**.

BUILDING MODEL

To model the H.R. MacMillan building, the software program OnScreen Takeoff was first used to measure, count and inventory the building elements. The measurements were then formatted in order to create a model of the building in the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings. This section details the process used for performing the takeoffs and discusses any assumptions and limitations throughout the whole modelling process. The bill of materials (BoM) is also presented, discussing the five largest amounts and how assumptions in the modelling process may have lead to deviations of material amounts. Lastly, the summary measures by life cycle stage are presented and further analyzed with a sensitivity analysis.

Takeoffs

In OnScreen Takeoff, three measurement conditions are used: linear, area, and count. After importing the architectural and structural drawings into the program and applying the appropriate scale factor, these conditions are used to inventory all the elements of the building to be considered. The linear condition records distances and was used for items such as walls, strip foundations, and height measurements. The area condition records areas and was used for items such as floors and roof area. The count condition records multiples of repeated items and was used for items such as pad footings, windows, and doors. The takeoffs were performed as precisely as practically possible, but some challenges arose during the process. Since the drawings were hand-drawn from 1967, the digital versions were scanned copies of the original. For this reason, there were instances where assumptions were used when poor quality (i.e. blurry sections or scan lines confused with dimension lines) affected the accuracy of the takeoffs. In addition, the accuracy of the building model was affected if required data was not available. For example, the size of rebar may not be specified and it would have to be assumed.

A number of assembly groups were modelled for entry into the Impact Estimator (IE); these include slab on grade foundations, footings, block walls, cast in place walls, curtain walls, columns and beams, suspended slab roofs, open web steel joist roofs, and concrete precast double tee floors. The following provides a description of each assembly group and how it was modelled, and any high-level assumptions that were made that affect all the inputs in the particular assembly group.

Concrete slabs on grade foundation

The concrete slab on grade (SOG) foundation at the floor of the ground level was modelled using the area condition. In the Impact Estimator (IE), there are two options for the SOG thickness: 4” or 8” thickness. In cases where the ideal rebar input was unavailable in the Impact Estimator, the next nearest option was selected and assumed for modelling purposes. The concrete flyash content was not specified in the drawings; it was assumed to be the average amount. Concrete is assumed to have a strength of 3000 psi for all cases unless otherwise noted, as specified. Also, the vapour barrier was assumed to be 6 mil, instead of 4 mil, as this was the only option in the IE.

Concrete footings

Concrete footings used to help form the building foundation were modelled using either the linear condition (e.g. strip/wall footings with specified cross-sectional dimensions) or the count condition (e.g. pad/column footings with specified dimensions). The IE limits the thickness of footings to 19.7". For footings thicker than this limit, the thickness was set to 19.7" and the width was increased accordingly to maintain equal volume. See drawings 386-07-009 and 386-07-010 for specifications of footing dimensions.

The linear condition was used to model the concrete stairs as footings. After measuring an average stair thickness (assumed to be 10”) and width, the length of stairs was measured using a linear condition. The internal stairs have a 1” plaster topping which was omitted as the IE does not have an option to add a layer of plaster to concrete footings.

The concrete columns inside the pilasters surrounding the exterior of the building are modelled as footings. The cross-sectional dimensions are specified (drawings 386-07-011 and drawings 386-07-013) and the lengths were measured using a linear condition. The pilaster columns contain various rebar sizes; #4 rebar was assumed to be the average.

For all concrete footings, the flyash content was not specified in the drawings; it was assumed to be the average amount. Concrete is assumed to have a strength of 3000 psi for all cases unless otherwise noted, as specified.

Concrete block walls

The majority of walls in the H.R. MacMillan building are concrete block walls. They were modelled using the linear condition for distances. The linear condition was also used to measure the wall height and it was found to be 12’. This value is used as an assumption for the heights of all walls. A different category was used to measure walls depending on the type of wall construction. Some walls have 1" rigid insulation (assumed to be 1" extruded polystyrene), modular brick cladding, or plaster finish, or a combination of these elements. A different category was also used for walls with differing openings, such as solid wood doors, glazed steel doors, or window openings. In the IE, concrete block walls are assumed to use 8" x 8" x 16" hollow concrete blocks with every third vertical core grouted and reinforced with one steel bar (assumed to be #4), and additional grouting and rebar is included at all openings. These conditions are assumed for all concrete block walls in MacMillan. For all instances where walls had a plaster finish, it was assumed to be regular 5/8" thick gypsum board (plaster is not available as an option in the IE). Even though operable windows are an option in the IE, all windows are considered fixed for conformity to the rest of the LCA studies conducted on other UBC buildings. Steel window frames are also assumed to be aluminum frames in the IE as there is no option for steel. All doors made from wood, including those that are glazed, are assumed to be solid wooden doors. Glazed aluminum doors were assumed to be 80% glazed.

Cast in place walls

Some of the walls of the ground floor are cast in place concrete walls. They were measured using the linear condition. Similar to concrete block walls, different categories were used to perform takeoffs depending on the wall construction and wall openings. All the same assumptions were made. Note that bituminous waterproof compound was omitted as it is not available in the IE.

Glazed curtain walls

Glazed curtain walls occur most often at the doorways to external and internal stairs. They are also modelled using the linear condition. It was assumed that the curtain walls had 90% viewable glazing and 10% opaque metal spandrel. The IE also requires a positive input for thickness of insulation. Since there was no insulation, this was assumed to be 0.0001. All the glazed metal doors were assumed to be 80% glazed aluminum doors.

Concrete columns and beams

Concrete columns and beams support the floors in H.R. MacMillan. The linear and count conditions were used to measure these elements. The count condition was used to measure the number of columns and beams. The linear condition was used to measure the floor to floor height.

The bay size measurement was obtained by using the linear condition to measure the total distance between a series of columns, then dividing that by the number of columns to produce the average bay size. The IE requires that the bay size be 10' or greater. The bay size was assumed to be 10' in cases where the average bay size was less than 10'. The supported span was obtained by using the linear condition to measure the total span, then dividing that by two to produce the average span. The total span was divided by two since the floors are supported at each external wall, and in between by one series of columns. In the IE, three options are available for the live load: 45 psf, 75 psf, and 100 psf. None of the specified live loads matched these options so the closest options were assumed. For labs and offices, 100 psf was used instead of the specified 120 psf (labs) and 50 psf (offices) for a conservative assumption. For classrooms, 45 psf was used instead of the specified 60 psf since 100 psf was an overestimation for labs and offices; this creates a more balanced overall estimate. For the third floor columns supporting the roof, 45 psf was used for the specified snow load of 40 psf. Note that the size of the columns and beams are calculated by metrics embedded in the IE.

Steel wide flange (WF) columns and beams

Steel wide flange columns and beams are used for the 'penthouse', which acts as a protective housing for the exhaust ducts from the labs. Similar to concrete columns and beams, the count condition was used to measure the number of columns and beams, and the linear condition was used to measure the floor to floor height. The same technique was used to obtain the average bay size. The calculated average bay size was 5.85' but it is assumed to be 10' due to this limitation in the IE.

Suspended slab roofs

A suspended slab roof is used for the H.R. MacMillan building. The linear condition was used to measure the width and spans of the roof. The IE requires the span input to be 30'. Thus for instances where the span is greater than 30', the span is set to 30' and the width is adjusted accordingly to maintain the same area. The live load was assumed to be 45 psi, the nearest option to the specified 40 psf snow load. The plaster finish was assumed to be regular 5/8" gypsum board as plaster is not available as an option in the IE. The 1" rigid insulation was assumed to be 1" extruded polystyrene. The flyash content was not specified in the drawings; it was assumed to be the average amount. Concrete is assumed to have a strength of 3000 psi for all cases unless otherwise noted, as specified.

Open web steel joist roofs

The roof of the 'penthouse' was assumed to be an open web steel joist roof. Similar to the suspended slab roof, the width and span was measured using the linear condition. In the IE, the span requires a minimum of 15.09'. The span was set to 15.09' and the width was adjusted accordingly to maintain the same area. It was assumed to be a commercial steel roof system.

Concrete precast double tee floors

Concrete precast tees are used for the flooring system. Although the precast tees in the H.R. MacMillan building are single and not double tees, this was assumed to be the case as it is the closest option. The count and linear condition was used to take measurements. The count condition was used to measure the number of bays and the linear condition was used to measure the bay size and the span size. The technique used to measure span size was the same as that used in concrete columns and beams. Due the span size being limited to 30', the span was set to 30' and the number of bays was adjusted accordingly to produce the equivalent floor size. The live load assumptions were the same as that used in concrete columns and beams.

Extra basic materials

In the Impact Estimator, additional materials can be entered manually to account for any components that are not covered by the default assembly groups. For the H.R. MacMillan building, this section was used to add concrete (20 MPa = 3000 psi) for the precast concrete caps that are on top of the pilasters and that surround the exterior edge at the roof. Modular brick was added for the penthouse walls and for the pilasters. Finally, mortar was added for the penthouse brick walls and the brick cladding on the pilasters.

Refer to **Appendix B** for the **Impact Estimator Input Assumptions**, which outlines all the high-level and specific assumptions, including detailed calculations, used in the IE model.

Bill of Materials

After all the inputs have been entered into the Impact Estimator, a bill of materials (BoM) can be generated to list all the materials and their amounts used in the building model. See **Table 2** for the BoM for the H.R. MacMillan building. Five materials with among the largest quantities are: 5/8" regular gypsum board, 3000 psi concrete (average flyash), concrete blocks, extruded polystyrene, and modular brick. The quantities of these materials have been affected by certain assumptions which could make them overestimations or underestimations.

Since plaster is not available in the Impact Estimator as a wall or roof envelope material, an assumption was made to replace plaster with 5/8" regular gypsum board in all cases where plaster existed for roofs and walls. Because of this assumption, the entire quantity of gypsum board is an overestimation. No gypsum board was shown to exist in the original drawings.

The 3000 psi concrete unsurprisingly shows up as one of the highest quantities as it was used for the foundations, cast in place walls, suspended slab roof, and in extra basic materials for the precast concrete caps. For all instances where the concrete strength was not specified, it was assumed to be 3000 psi. This was noted in the General Notes in drawing 386-07-009. However, the concrete caps were precast, meaning they were made at a manufacturing plant away from the site. If the manufacturing company used a different type of concrete, not 3000 psi, then the quantity in the BoM has been overestimated due to the "6.1.1 - Precast Concrete Cap for Pilaster Col'n 0,1,2,3FL Types A,B,H,M" and "6.1.2 - Precast Concrete Cap linear" inputs.

For concrete blocks, assumptions were made regarding the heights of various walls. To a certain extent, the lengths of various walls were assumed as well. For example, there was no drawing provided for the wall layout of the north side of the ground floor. Thus, the walls lengths (0FL - Int - 8" conc blk (corridor typ)" were estimated based on a physical site visit of the building. It was also assumed that all concrete block walls used the same concrete block wall construction as is defined in the IE, which is not the case for the real building. Adding up the total effects of the assumed wall dimensions, combined with the assumption that all concrete blocks are the same, this could lead to an overestimation or underestimation of the quantity of concrete blocks in the BoM.

Extruded polystyrene was assumed to be used when the drawings specified 1" rigid insulation. It is assumed that all parts of the roofs and exterior walls (e.g. "2.1.5 - 1FL - Ext - 6" conc blk - 1" insul - brick (lab typ)") contain this layer of insulation. However, it is not known if extruded polystyrene was actually used as the insulation in the building. If it wasn't, then the quantity in the

BoM is a 100% overestimation. Assuming that extruded polystyrene was used, the assumption that all exterior walls and roofs used this could overestimate the amount in the BoM if it wasn't actually used in everywhere in these particular walls and roofs.

For modular brick, it was assumed to be used on all exterior wall surfaces, as well as on the pilasters, and on some internal walls. However, on the actual building, it can be seen that not the entire exterior walls are clad with brick. There is a strip of exposed concrete between each storey. This (e.g. "2.1.7 - 1FL - Ext - plaster - 6" conc blk - 1" insul - brick (office typ)" leads to an overestimation in the BoM quantity.

Table 2 – H.R. MacMillan Bill of Materials

Material	Quantity	Unit
5/8" Regular Gypsum Board	131497.3116	sf
6 mil Polyethylene	37588.32865	sf
Aluminium	27.92154	Tons
Cold Rolled Sheet	1.0976	Tons
Concrete 3000 psi (flyash av)	8121.74553	yd3
Concrete 4000 psi (flyash av)	2991.97628	yd3
Concrete 9000 psi (flyash av)	4586.47272	yd3
Concrete Blocks	209116.0703	Blocks
EPDM membrane	3389.29863	Pounds
Expanded Polystyrene	140.14611	sf (1")
Extruded Polystyrene	100774.5279	sf (1")
Galvanized Decking	5.48816	Tons
Galvanized Sheet	3.87601	Tons
Glazing Panel	20.38485	Tons
Joint Compound	11.05878	Tons
Metric Modular (Modular) Brick	104422.7401	sf
Modified Bitumen membrane	1152.15121	Pounds
Mortar	1097.65832	yd3
Nails	131.75873	Tons
Open Web Joists	2.23293	Tons
Paper Tape	0.12689	Tons
Rebar, Rod, Light Sections	334.33651	Tons
Screws Nuts & Bolts	0.77143	Tons
Small Dimension Softwood Lumber, kiln-dried	12.40757	Mbfm
Solvent Based Alkyd Paint	10.85478	US gallons
Standard Glazing	15825.20873	sf
Water Based Latex Paint	45.71523	US gallons
Welded Wire Mesh / Ladder Wire	32.16381	Tons
Wide Flange Sections	9.9912	Tons

Summary Measures

After the inputs have been entered into the Impact Estimator, a results report of summary measures can be generated showing the environmental effects of the building model by life cycle stage (or by assembly group). The Impact Estimator can produce a report of summary measures for five life cycle stages: manufacturing, construction, maintenance, end-of-life, and operating energy. For the purpose of this LCA, only the manufacturing and construction stages are considered. The effects of the H.R. MacMillan building are shown in **Table 3**. The summary measures are the output assessment results for the building's impacts for eight environmental impact categories, based on the US EPA's midpoint impact estimation Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): embodied primary energy consumption, weighted raw resource use, global warming potential, acidification potential, human health respiratory effects potential, aquatic eutrophification potential, ozone depletion potential, and photochemical smog potential.

Table 3 - Summary Measures by Life Cycle Stage

	Impact Category							
	Primary Energy Consumption	Weighted Resource Use	Global Warming Potential	Acidification Potential	HH Respiratory Effects Potential	Eutrophi-cation Potential	Ozone Depletion Potential	Smog Potential
	MJ	kg	(kg CO2 eq / kg)	(moles of H+ eq / kg)	(kg PM2.5 eq / kg)	(kg N eq / kg)	(kg CFC-11 eq / kg)	(kg NOx eq / kg)
Manufacturing								
Material	57,453,810	37,266,745	5,514,303	1,760,862	14,822	104.39	0.01	21,106
Transportation	1,323,886	41,088	2,307	790	0.95	0.01	0.00	17.81
Total	58,777,696	37,307,833	5,516,610	1,761,651	14,823	104.40	0.01	21,124
Construction								
Material	1,473,406	67,684	101,997.41	51,324	54.83	0.00	0.00	2,025
Transportation	6,028,675	137,201	9,705.58	3,156	3.80	0.02	0.00	70.65
Total	7,502,081	204,885	111,703.00	54,479	58.62	0.02	0.00	2,095
Total Effects								
Overall	66,279,777	37,512,718	5,628,313	1,816,131	14,882	104.42	0.01	23,220
Per sq.ft.	437.12	247.40	37.12	11.98	0.10	0.00	0.00	0.15

Primary energy consumption

Primary energy consumption is all the embodied primary energy, including all direct and indirect energy used to make a product from raw material extraction to the finished product. In the Impact Estimator, it is reported in megajoules (MJ). This category encompasses the energy used in all processes of the product's creation, including energy associated with powering manufacturing machines. The Impact Estimator also accounts for indirect energy use associated with transporting, converting and delivering fuel and energy. The higher the embodied energy, the less desirable it is as it means more energy was required to produce the item. Each component in the building model has an effect on embodied energy. Since even small components can have a large embodied energy, the uncertainty in the building model can create very imprecise primary energy consumption values.

Weighted raw resource use

Raw resource use is the amount of raw resources used in the production of a building material or product, and is reported in kilograms (kg). However, since resources cannot be compared by a unit mass, a weighting factor is applied. For example, a unit of timber cannot be compared to a unit of metal ore. The weighting index numbers that the Impact Estimator reference were established through a survey of a number of resource extraction and environmental specialists across Canada. The value that the Impact Estimator reports is a summed total of the raw resource usage after applying the index numbers. The factored numbers can be thought of as 'ecologically weighted kilograms' but the weighting is reflective of the opinions of the surveyed experts. As with embodied energy, all components have an effect on this impact category as raw materials are required to produce any building product or material. However, it is uncertain how much each product or assembly group affects the final reported value.

Global warming potential

Global warming potential is the measure of a product or material's potential to contribute to global warming via the greenhouse effect, and is measured relative to the effect of carbon dioxide (CO_2). The units are in kilograms or tonnes CO_2 equivalent. The effect of all other chemicals is assigned a multiple of the CO_2 equivalent. Due to the unknown reactivity and stability of chemicals in the atmospheric environment, the temporal effects of chemicals on global warming are uncertain. Greenhouse gas emissions are primarily produced when fuels are combusted, but some products also produce emissions during manufacture or processing. The Impact Estimator uses a detailed life cycle modelling technique that captures all the relevant emissions, including any released during processing. Uncertainty arises in modelling greenhouse gas emissions and global warming potential as it is difficult to account for emissions produced during complex processes, such as those for manufacture.

Acidification potential

Acidification potential is a regional effect that concerns human health and the health of other living organisms. The acidification potential of air or water emissions are calculated based on of its H+ equivalence effect on a mass basis. It is reported in moles of H+ equivalent/kg. High concentrations of NO_x and SO_2 are thought to produce adverse effects on life. However, much uncertainty is present in this field as it is not yet widely understood.

Human health respiratory effects potential

Human health respiratory effects potential deals with the effects particulate matter have on human health, particularly the respiratory system. Particulates have a serious impact on human health, e.g. the EPA says particulates from diesel fuel combustion are the number one source of respiratory deterioration and diseases such as asthma and bronchitis. This impact category is reported in kg PM2.5 equivalent/kg.

Aquatic eutrophification potential

Eutrophication is the process of enriching previously nutrient scarce surface water bodies with more nutrients and is measured relative to nitrogen equivalents. The addition of nutrients to a body of water leads to an increase in photosynthetic aquatic plant life (e.g. algae). The new growth can dominate and devastate natural species and cause other consequences such as foul odours or dead fish. Aquatic eutrophication potential is reported in kg N equivalent/kg.

Ozone depletion potential

Ozone depletion potential measures impacts related to the reduction of ozone layer within the stratosphere. This is a protective layer in the atmosphere which absorbs the large majority of the sun's ultraviolet light. The depletion is caused by emissions of ozone depleting substances, including CFCs, HFCs, and halons. The ozone depletion potential of each of a chemical or substance is measured relative to CFC-11, and is reported in kg CFC-11 equivalent/kg.

Photochemical smog potential

Smog is a type of air pollution, the product of industrial and/or transportation emissions being trapped close to ground level where it reacts under certain atmospheric condition with sunlight. Smog is a serious issue affecting human health in many cities. Industries release nitrogen oxides (NOx) and other man-made products release volatile organic compounds (VOCs). Such compounds can severely affect people with heart and lung diseases such as bronchitis and asthma. Smog potential is reported in kg NOx equivalent/kg.

Sensitivity Analysis

To analyze the relative effects that materials have on each of the TRACI impact categories, a sensitivity analysis for five materials was completed. The summary measures were re-evaluated after adding and subtracting 10% of the material from the Bill of Materials for the following materials: concrete (20 MPa = 3000 psi), concrete (60 MPa = 9000 psi), concrete blocks, extruded polystyrene, and modular brick. The effects on each of the impact categories are shown in **Table 4**. The highlighted values are those with the largest impact for a given impact category. Note that the waste factors inherent to the Impact Estimator when manually adding or subtracting materials was not accounted for this sensitivity analysis.

Table 4 - Sensitivity Analysis Percentage Results
on Construction and Manufacturing Life Cycle Stages

	Impact Category							
	Primary Energy Consumption	Weighted Resource Use	Global Warming Potential	Acidification Potential	HH Respiratory Effects Potential	Eutrophi-cation Potential	Ozone Depletion Potential	Smog Potential
	MJ	kg	(kg CO2 eq / kg)	(moles of H+ eq / kg)	(kg PM2.5 eq / kg)	(kg N eq / kg)	(kg CFC-11 eq / kg)	(kg NOx eq / kg)
Concrete+10% (20 MPa)	1.37%	4.49%	2.24%	2.33%	2.14%	0.07%	3.35%	2.76%
Concrete-10% (20 MPa)	-1.37%	-4.49%	-2.24%	-2.33%	-2.14%	-0.07%	-3.35%	-2.76%
Concrete+10% (60 MPa)	1.09%	2.74%	1.94%	2.05%	1.70%	0.05%	2.99%	2.45%
Concrete-10% (60 MPa)	-1.09%	-2.74%	-1.94%	-2.05%	-1.70%	-0.05%	-2.99%	-2.45%
Concrete Blocks+10%	0.67%	0.08%	0.80%	0.89%	0.75%	0.04%	0.92%	0.77%
Concrete Blocks-10%	-0.67%	-0.08%	-0.80%	-0.89%	-0.75%	-0.04%	-0.92%	-0.77%
Extruded Polystyrene+10%	0.11%	0.01%	0.06%	0.06%	0.01%	0.00%	0.00%	0.31%
Extruded Polystyrene-10%	-0.11%	-0.01%	-0.06%	-0.06%	-0.01%	0.00%	0.00%	-0.31%
Brick+10%	2.28%	0.31%	1.50%	1.86%	1.43%	0.07%	0.00%	0.10%

Brick-10%	-2.30%	-0.31%	-1.51%	-1.88%	-1.44%	-0.07%	0.00%	-0.10%

From the results shown in Table 4, it can be seen that 3000 psi concrete has the largest effect in every impact category, except embodied primary energy which modular brick has the biggest effect in. Brick also has an equal effect to 3000 psi concrete in eutrophification potential. Interesting, 9000 psi (primarily used for the precast concrete double tees) had much less of an effect than the 3000 psi concrete. Also interesting is that extruded polystyrene had minimal effect in any of the impact categories. It was expected to have a greater effect due to its chemical nature. Comparing concrete blocks to the 3000 and 9000 psi concrete is also interesting. The effects of the concrete blocks are small compared to the both types of concrete, even though all three are made from concrete.

This type of analysis is very valuable when performing an LCA on a building at the design stage or the renovation stage as it shows the potential impacts before the building is built or renovated. For example, from this analysis, one can conclude that building a brick wall instead of a concrete wall is a better choice since bricks have a much less impact on each of the impact categories (except embodied primary energy and eutrophification potential) compared to 3000 psi concrete.

The following graphs compare the effect of adding or subtracting 10% of the five materials for each impact category. The amounts are separated into the manufacturing and construction life cycle stages.

Figure 2 shows the sensitivity analysis for embodied primary energy. One can conclude from this graph that the majority of the embodied energy is in the manufacturing of the materials, and not in their construction/transportation stage. As mentioned in the previous section, modular brick has the largest effect on embodied primary energy.

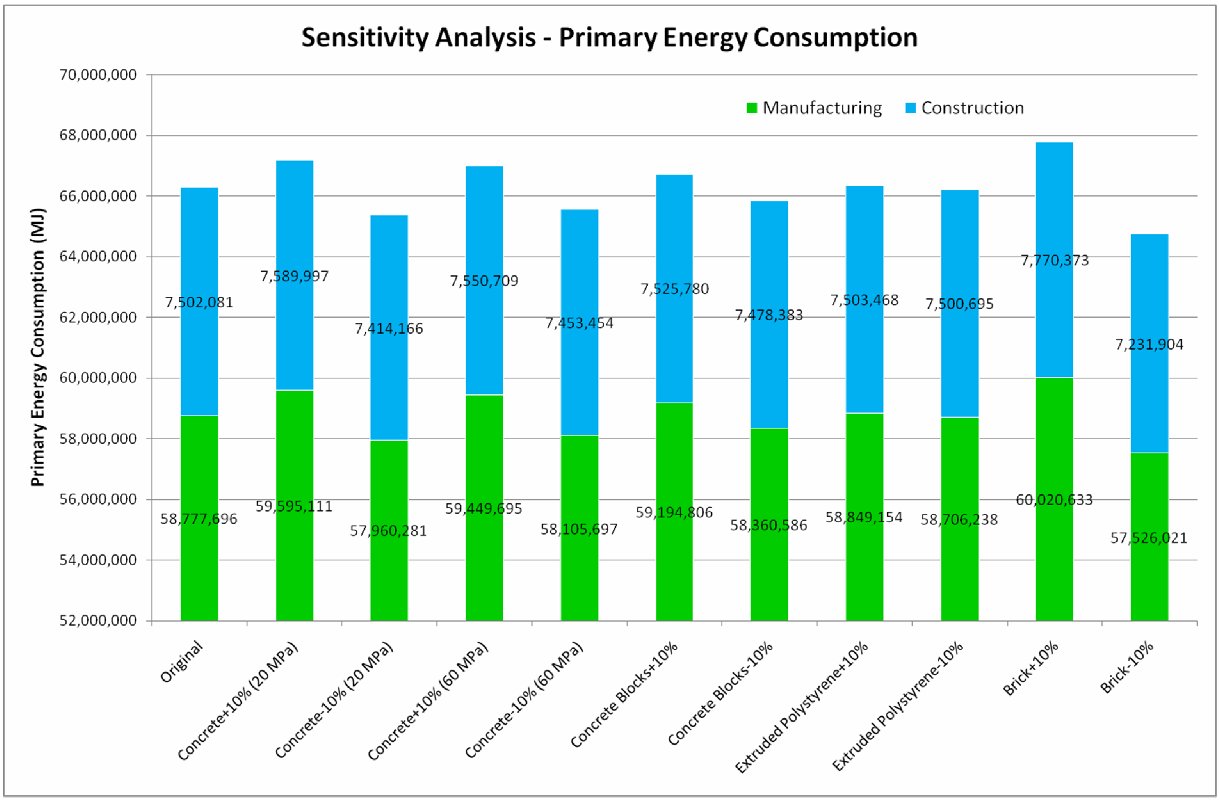

Figure 2 - Sensitivity Analysis of Primary Energy Consumption

Figure 3 shows the sensitivity analysis for weighted raw resource consumption. One can conclude from this graph that the large majority of raw resources are consumed in the manufacturing stage. The construction/transportation stage represents a very small amount of resource consumption. Concrete (20 MPa = 3000 psi) has the largest effect of resource consumption by far.

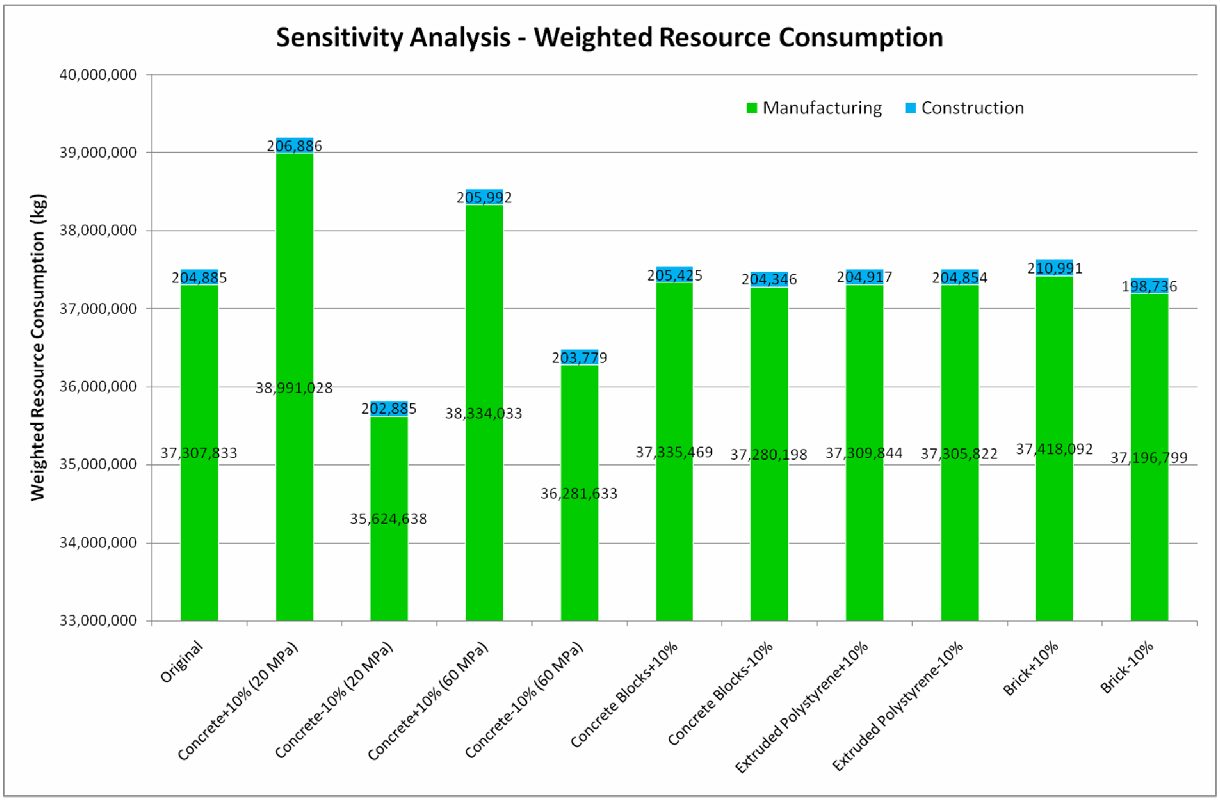

Figure 3 – Sensitivity Analysis of Weighted Resource Consumption

Figure 4 shows the sensitivity analysis for global warming potential. One can conclude from this graph that the majority of global warming potential is produced in the manufacturing stage. The construction/transportation stage represents a much smaller potential. Concrete (20 MPa = 3000 psi) has the largest global warming potential, followed by modular brick.

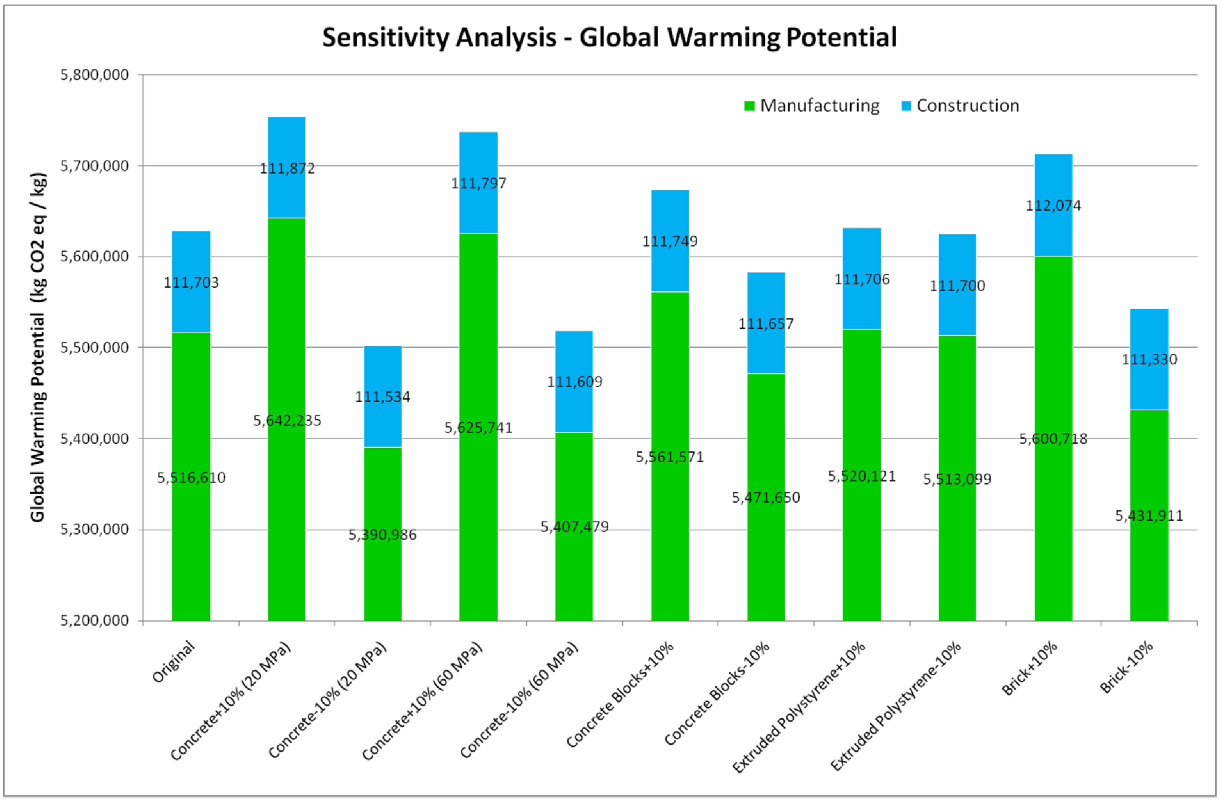

Figure 4 - Sensitivity Analysis of Global Warming Potential

Figure 5 shows the sensitivity analysis for acidification potential. One can conclude from this graph that the large majority of acidification potential is developed in the manufacturing stage. Concrete (20 MPa = 3000 psi) has the largest acidification potential, closely followed by modular brick.

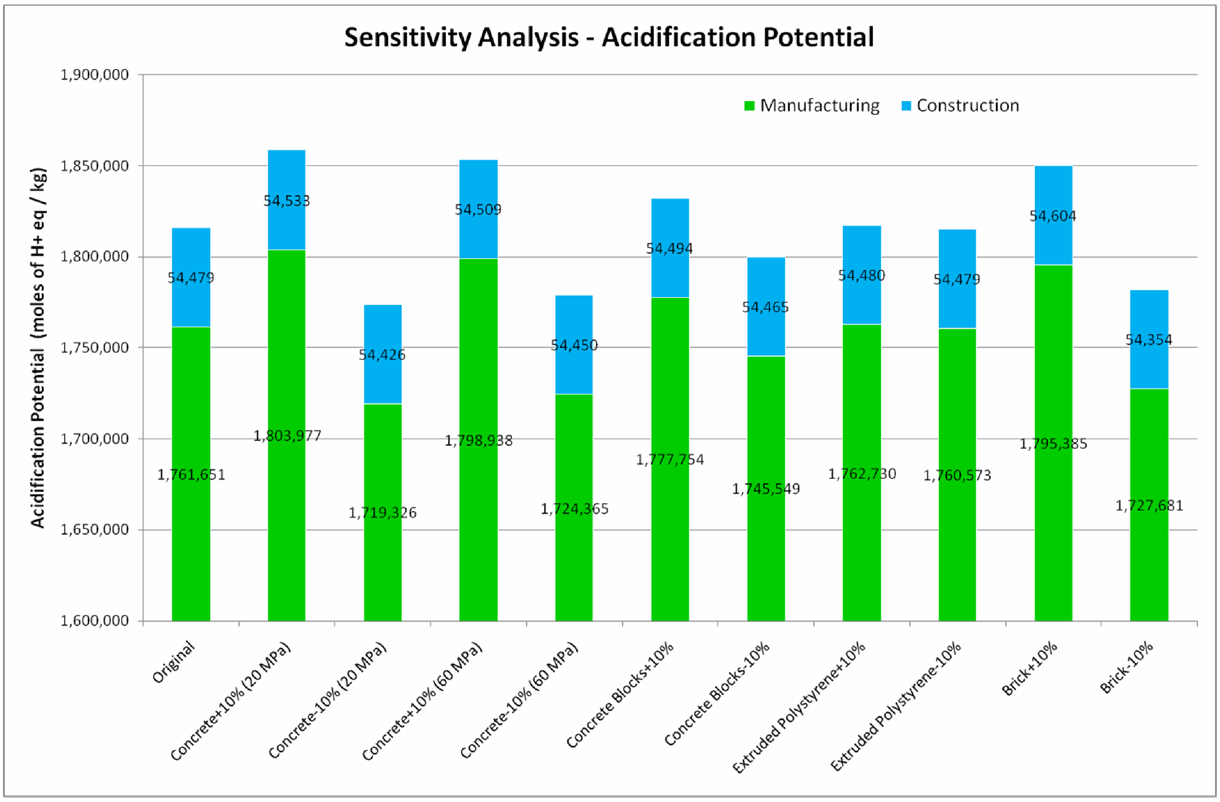

Figure 5 - Sensitivity Analysis of Acidification Potential

Figure 6 shows the sensitivity analysis for human health respiratory effects potential. One can conclude from this graph that the manufacturing stage creates a large cause for concern for respiratory effects. The construction/transportation stage represents a relatively small concern. The two types of concretes have the highest effect in this impact category.

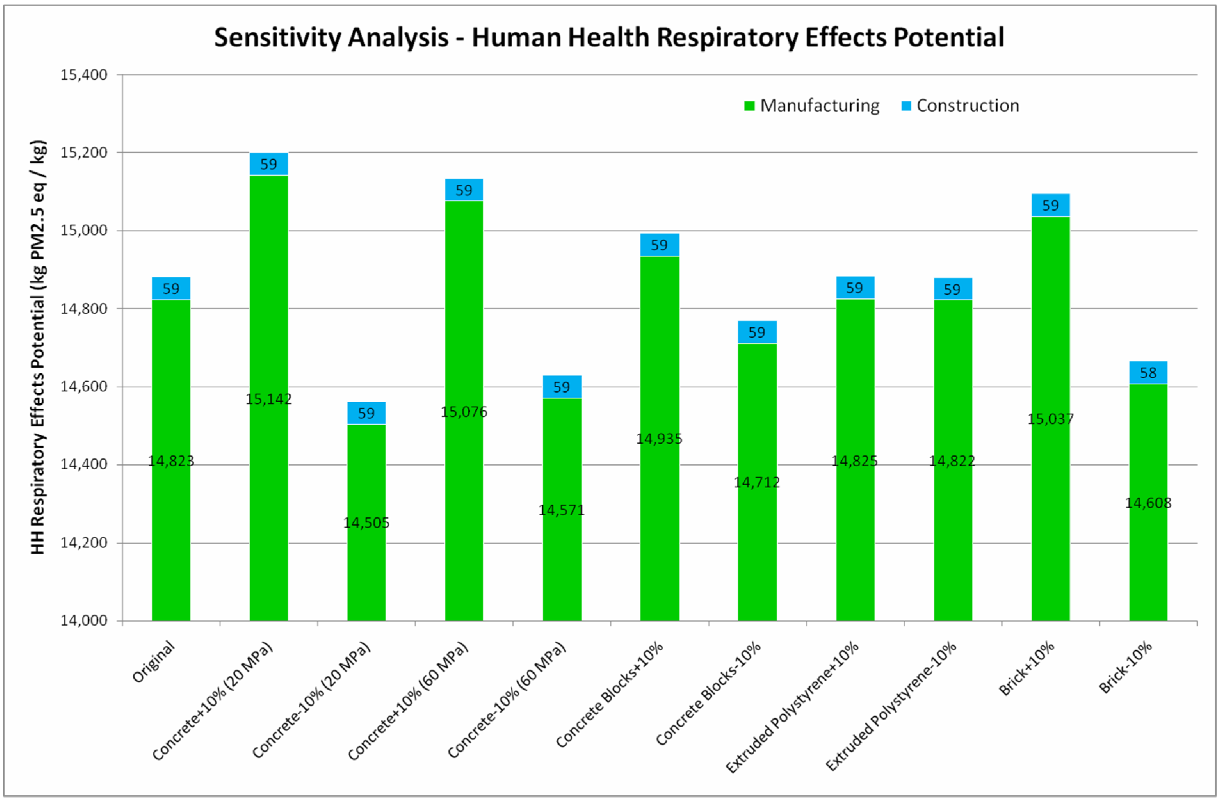

Figure 6 - Sensitivity Analysis of Human Health Respiratory Effects Potential

Figure 7 shows the sensitivity analysis for eutrophification potential. One can conclude from this graph that the large majority of eutrophification potential is developed in the manufacturing stage. The construction/transportation stage represents a tiny amount compared to manufacturing. Concrete (20 MPa = 3000 psi) and modular brick have the same, largest effect.

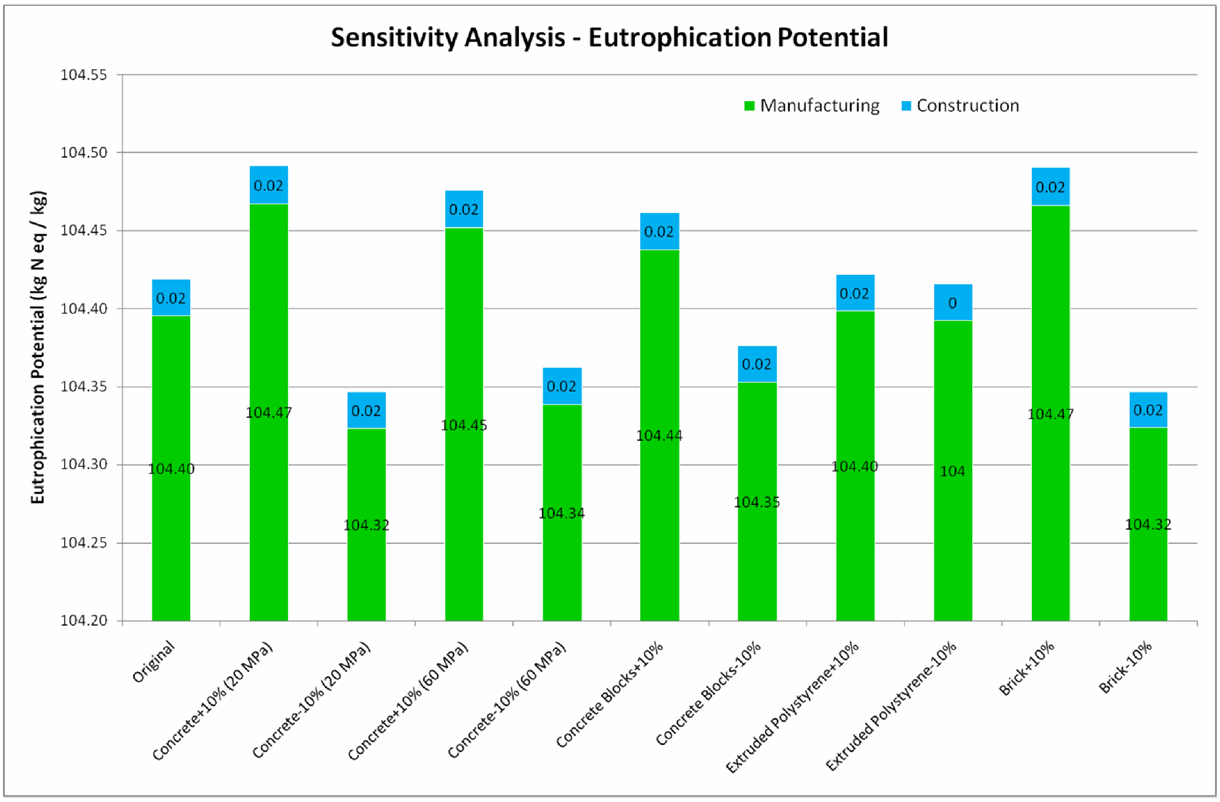

Figure 7 - Sensitivity Analysis of Eutrophication Potential

Figure 8 shows the sensitivity analysis for ozone depletion potential. One can conclude from this graph that all of the ozone depletion potential is due to the manufacturing of materials. The two types of concretes have the biggest effect on ozone depletion by far.

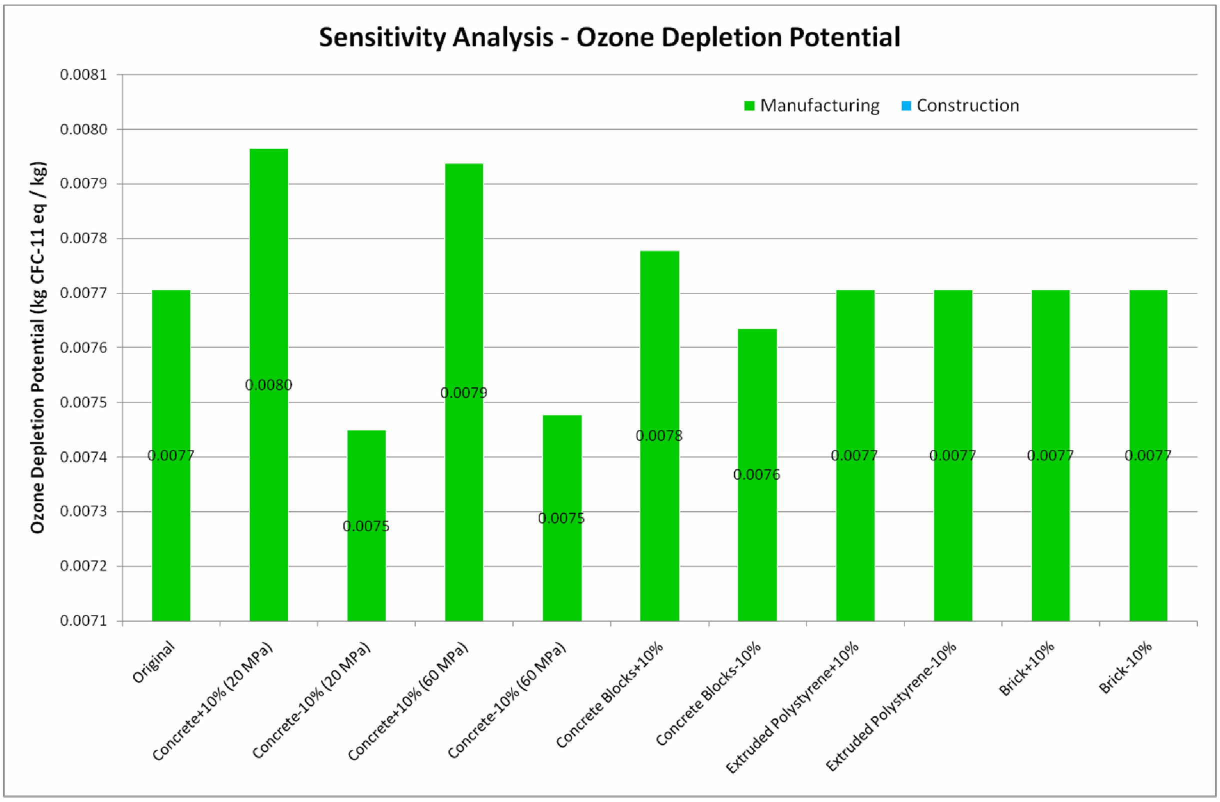

Figure 8 - Sensitivity Analysis of Ozone Depletion Potential

Figure 9 shows the sensitivity analysis for smog potential. One can conclude from this graph that the large majority of smog potential is developed in the manufacturing stage. The construction/transportation stage represents a small amount of in comparison to manufacturing. The two types of concretes have the largest effects on smog potential.

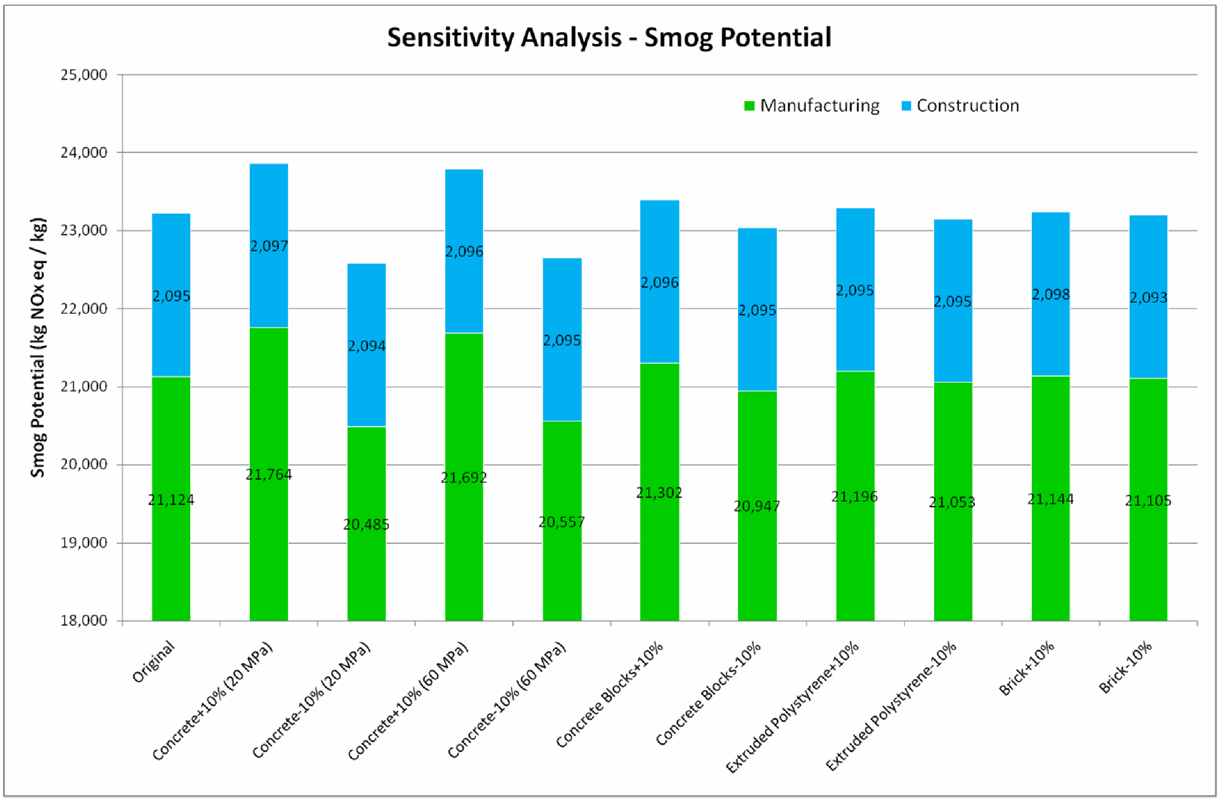

Figure 9 - Sensitivity Analysis of Smog Potential

Based on Figures 2 to 9, it can be seen that the effects on all impact categories are primarily due to the manufacturing stage of the materials.

BUILDING PERFORMANCE

It is also important to analyze operational energy building performance in an LCA, if possible. The insulation in the walls and roofs is the main element that traps the heat and prevents it from being lost to the external environment (in heating dominated climates such as Vancouver). To determine the best type of insulation (available in the Impact Estimator) in terms of performance and embodied energy, the manufacturing embodied energy for one square feet of one inch of each type of insulation was evaluated. The embodied energy in the construction was omitted as it was relatively much less. The results are presented in **Table 5** with the R-value for one inch of corresponding insulation.

Table 5 – Comparison of Insulation Types with Embodied Energy

Insulation	Fiberglass Batt	Rockwool Batt	Blown Cellulose	Expanded Polystyrene	Extruded Polystyrene	Foam Poly-isocyanurate
Embodied Energy (MJ)	1.56	2.45	0.174	3.60	7.19	6.11
R-value	3.14	3.14	3.10	4.00	5.00	6.25
Embodied Energy/ R-value	0.50	0.78	**0.06**	0.90	1.44	0.98

From Table 5, after normalizing the embodied energy to R-values, blown cellulose is by far the lowest embodied energy per R-value. However, it also has the lowest R-value per inch of material. This means it would take 13" (ie. 40/3.1) of blown cellulose to reach the R-40 requirement for roofs under the Residential Environmental Assessment Program (REAP) standards. This is obviously impractical for renovation purposes. The foam polyisocyanurate is a good candidate as replacement insulation. It has a relatively high embodied energy to R-value ratio but the highest R-value per inch. It would only take 40/6.25 = 6.4" to achieve the R-40 requirement for roofs. This is much more practical. Since it has such a high R-value, the energy payback period due to savings from operational energy loss is much quicker.

Figure 10 compares the energy usage between the current insulation versus the same building with insulation improved to REAP standards (R-40 for roofs, R-18 for walls). For the purpose of this analysis, the energy usage is assumed to be the same as the energy loss. These energy loss values are calculated using this formula: $Q = (1/R)A\Delta T$, where R is the R-value of the insulation, A is the area of the material (insulation) undergoing conductive heat transfer, and ΔT is the temperature difference between the inside of the building and the outside ambient temperature.

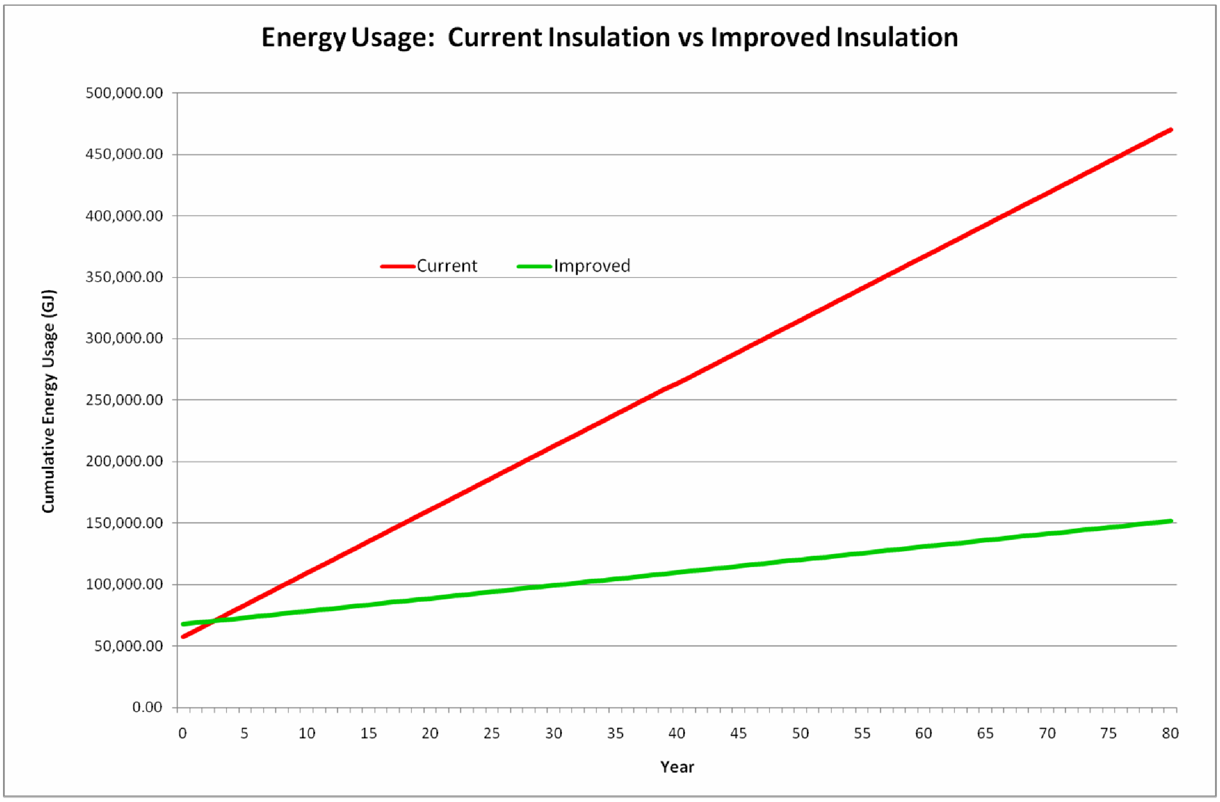

Figure 10 - Comparison of Energy Usage of Current Insulation vs Improved Insulation

Three building components are considered for this calculation: exterior walls, windows, and roofs. The areas of these components are measured from OnScreen Takeoff using linear and area conditions. The current R-values of the components are 5.0, 0.91, and 5.0, respectively. The embodied energy from the Impact Estimator summary measures is the initial embodied primary energy of the building with the current insulation. Then, the building model is adjusted by removing the current insulation and 'new' insulation was added to meet REAP standards. 2.5" of polyisocyanurate (R-7.2/inch) for the walls and 5.6" of polyisocyanurate for the roof were added. The windows were also changed to low E silver argon filled glazed windows (R-3.75). The embodied energy of this improved building was re-evaluated. The embodied energies of the current and improved buildings are entered at year 0 (when the building was hypothetically constructed). Using the heat transfer formula described above, the cumulative energy usage (loss) is calculated. From Figure 10, the payback is where the two lines intersect. That is, even though the embodied energy of the improved building is higher due to more insulation, it would only take 2 to 3 years before the building with the improved insulation would save more energy compared to the current building. That represents significant energy savings, especially considering the steam energy consumption used per year (**Figure 11**).

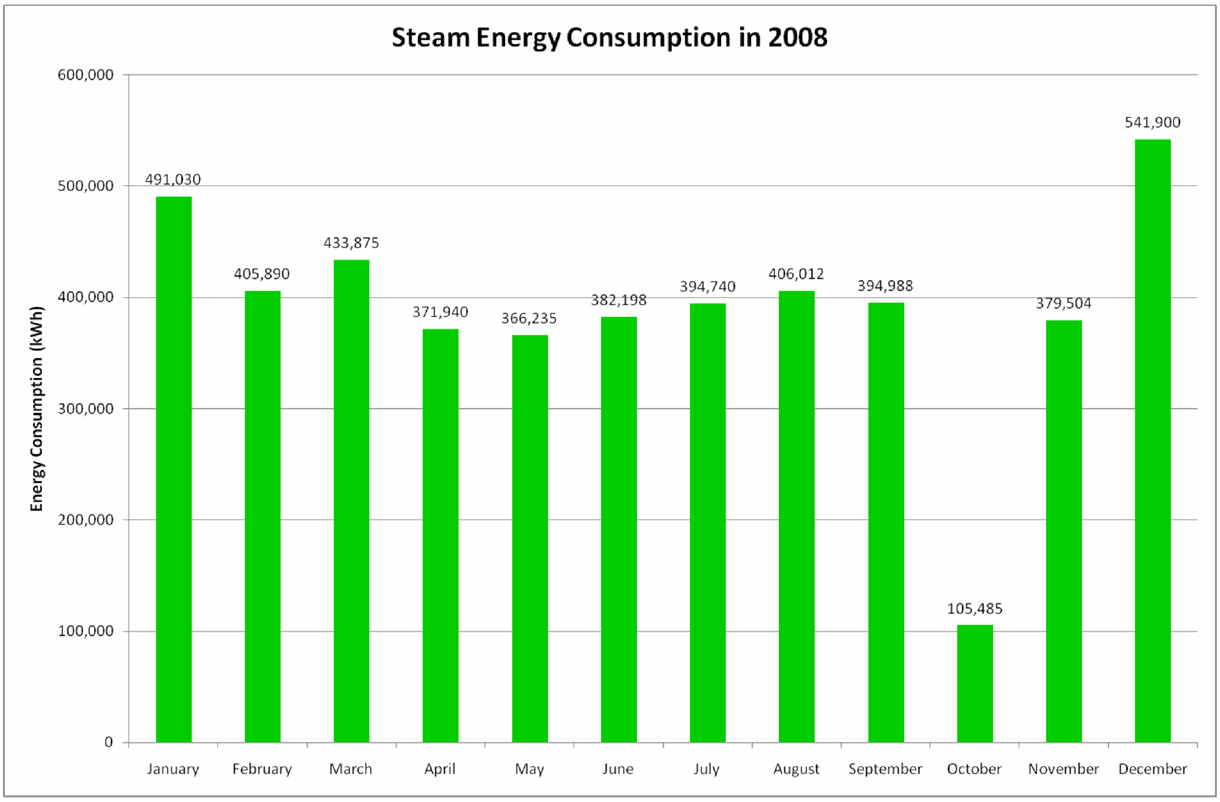

Figure 11 - Consumption of Steam Energy in 2008

CONCLUSIONS

After creating the building model in the Athena Sustainable Materials Institute's Impact Estimator (IE), a Bill of Materials and summary measure reports were generated. The results of the summary measures, normalized to per square foot of usable building space, are: 437 MJ embodied energy, 250 kg of weighted raw resource use, 37 kg CO_2 equivalent/kg global warming potential, 12 moles H+ equivalent/kg acidification potential, 0.10 kg PM2.5 equivalent/kg respiratory effects potential, 104 kg N equivalent/kg eutrophification potential, less than 0.01 kg CFC-11 equivalent/kg ozone depletion potential, and 0.15 kg NOx equivalent/kg photochemical smog potential. Compared to the averaged results from the other LCA studies completed for academic buildings, the H.R. MacMillan building has a higher value for every impact category except for eutrophification potential and ozone depletion potential. In these two categories, the final values are too small and too close to draw definite conclusions. These results mean that the H.R. MacMillan building has a higher environmental impact compared to the average UBC academic building.

A sensitivity analysis was completed to analyze the relative effects of five materials. Concrete (20 MPa = 3000 psi) and modular bricks had by far the largest effects in each of the impact categories. Also from the sensitivity analysis, it was concluded that the large majority of the effects in the impact categories occurred in the manufacturing life cycle stage, and not in the construction stage. An analysis was also completed to assess the performance of the building. The current insulation of the building was compared to improved insulation to meet Residential Environmental Assessment Program (REAP) standards. The payback period of the building with the improved insulation was found to be between two to three years.

The results of this LCA are very important to analyze the building design and construction elements, as well as to assess potential upgrades to the building. Namely, improved insulation could significantly reduce the operational energy consumption. When these results are combined with the other LCA studies of other buildings on campus, it creates a powerful network of information from which to make informed decisions or to make new assessments. It is recommended that these results be shared with sustainability groups, the building and construction industry, as well as the University of British Columbia community.

APPENDIX A – FORMATTED INPUTS

General Description					
	Project Name		H.R. MacMillan		
	Project Location		Vancouver		
	Building Life Expectancy		1 year		
	Building Type		Institutional		
	Operating Energy Consumption		1,329,042 kWh/month		
Assembly Group	**Assembly Type**	**Assembly Name**	**Input Fields**	**Input Values**	
				Known/Measured	EIE Inputs
1 Foundation					
	1.1 Concrete Slab on Grade				
		1.1.1 - Slab 4" thick #3			
			Length (ft)	100	100
			Width (ft)	354.34	354.34
			Thickness (in)	4	4
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 4 mil	Polyethylene 6 mil
		1.1.2 - Slab 8" thick #4			
			Length (ft)	100	100
			Width (ft)	9.34	9.34
			Thickness (in)	8	8
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
	1.2 Concrete Footing				
		1.2.1 - Ftg Linear 14" x 10"			
			Length (ft)	25	25
			Width (ft)	1.17	1.17
			Thickness (in)	10	10
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average

	Rebar	#5	#5
1.2.2 - Ftg Linear 14" x 12"			
	Length (ft)	147	147
	Width (ft)	1	1
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.3 - Ftg Linear 16" x 10"			
	Length (ft)	19	19
	Width (ft)	1.33	1.33
	Thickness (in)	10	10
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.4 - Ftg Linear 16" x 12"			
	Length (ft)	150	150
	Width (ft)	1.33	1.33
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.5 - Ftg Linear 20" x 12"			
	Length (ft)	1460	1460
	Width (ft)	1.67	1.67
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.6 - Ftg Linear 24" x 10"			
	Length (ft)	34	34
	Width (ft)	2	2
	Thickness (in)	10	10
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.7 - Ftg Linear 28" x 10"			
	Length (ft)	178	178
	Width (ft)	2.33	2.33

			Thickness (in)	10	10
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.8 - Ftg Linear 34" x 12"			
			Length (ft)	15	15
			Width (ft)	2.83	2.83
			Thickness (in)	12	12
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.9 - Ftg Linear 36" x 24"			
			Length (ft)	703	703
			Width (ft)	3.00	3.65
			Thickness (in)	24	19.7
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.10 - Ftg Linear 38" x 12"			
			Length (ft)	33	33
			Width (ft)	3.17	3.17
			Thickness (in)	12	12
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.11 - Ftg Pad 2'10" x 5'0" 1'0" deep #5			
			Length (ft)	2.83	2.83
			Width (ft)	5	5
			Thickness (in)	12	12
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.12 - Ftg Pad 3'10" x 3'0" 1'0" deep #5			
			Length (ft)	3.83	3.83
			Width (ft)	3	3
			Thickness (in)	12	12
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5

		1.2.13 - Ftg Pad 4'0" sq 1'3" deep #5			
			Length (ft)	4	4
			Width (ft)	4	4
			Thickness (in)	15	15
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.14 - Ftg Pad 4'6" sq 1'3" deep #5			
			Length (ft)	4.5	4.5
			Width (ft)	4.5	4.5
			Thickness (in)	15	15
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.15 - Ftg Pad 4'6" sq 1'3" deep #6			
			Length (ft)	4.5	4.5
			Width (ft)	4.5	4.5
			Thickness (in)	15	15
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#6	#6
		1.2.16 - Ftg Pad 4'6" x 5'2" 1'9" deep #5			
			Length (ft)	4.5	4.5
			Width (ft)	5.17	5.51
			Thickness (in)	21	19.7
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.17 - Ftg Pad 5'0" sq 1'6" deep #5			
			Length (ft)	5	5
			Width (ft)	5	5
			Thickness (in)	18	18
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#5	#5
		1.2.18 - Ftg Pad 5'2" sq 1'6" deep #5			
			Length (ft)	5.17	5.17
			Width (ft)	5.17	5.17
			Thickness (in)	18	18

	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.19 - Ftg Pad 5'6" sq 1'6" deep #5			
	Length (ft)	5.5	5.5
	Width (ft)	5.5	5.5
	Thickness (in)	18	18
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.20 - Ftg Pad 5'9" sq 1'9" deep #6			
	Length (ft)	5.75	5.75
	Width (ft)	5.75	7.01
	Thickness (in)	24	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#6
1.2.21 - Ftg Pad 6'6" sq 2'0" deep #6			
	Length (ft)	6.5	6.5
	Width (ft)	6.5	7.92
	Thickness (in)	24	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#6	#6
1.2.22 - Ftg Pad 7'0" x 5'6" 1'10" deep #6			
	Length (ft)	7	7
	Width (ft)	5.5	6.14
	Thickness (in)	22	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#6	#6
1.2.23 - Ftg Pad 7'6" x 6'0" 2'0" deep #6			
	Length (ft)	7.6	7.6
	Width (ft)	6	7.31
	Thickness (in)	24	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#6
1.2.24 - Stair #1,4 - #4 - 1" plaster topping			

	Length (ft)	276	276
	Width (ft)	4.25	4.25
	Thickness (in)	10	10
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#4	#4
1.2.25 - Stair #2,3 - #4 - 1" plaster topping			
	Length (ft)	342	342
	Width (ft)	7.33	7.33
	Thickness (in)	10	10
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#4	#4
1.2.26 - Stair ext - #4			
	Length (ft)	23	23
	Width (ft)	6	6
	Thickness (in)	10	10
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#4	#4
1.2.27 - Pilaster Col'n 0FL Type A 1'0" x 1'7"			
	Length (ft)	1500	1500
	Width (ft)	1.58	1.58
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#4	#4
1.2.28 - Pilaster Col'n 0FL Type B 1'0" x 1'9"			
	Length (ft)	3100	3100
	Width (ft)	1.75	1.75
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#4	#4
1.2.29 - Pilaster Col'n 0FL Type C 1'0" x 1'9"			
	Length (ft)	234	234
	Width (ft)	1.75	1.75
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average

			Rebar	#4	#4
		1.2.30 - Pilaster Col'n 0FL Type D 1'0" x 1'7" #7Vert			
			Length (ft)	663	663
			Width (ft)	1.75	1.75
			Thickness (in)	12	12
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#4
		1.2.31 - Pilaster Col'n 1,2,3FL Type H 1'2.5" x 8" #5Vert			
			Length (ft)	1419	1419
			Width (ft)	0.67	0.67
			Thickness (in)	14.5	14.5
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#4
		1.2.32 - Pilaster Col'n 1,2,3FL Type M 1'11" x 1'1.5" #5Vert			
			Length (ft)	510	510
			Width (ft)	1.25	1.25
			Thickness (in)	13.5	13.5
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#4	#4
2 Custom Wall					
	2.1 Concrete Block Wall				
		2.1.1 - 0FL - Int - 4" conc blk - brick (partial corridor)			
			Wall Type	Interior	Interior
			Length (ft)	308	308
			Height (ft)	12	8
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	8	8

			Door Type	Solid wood door	Solid wood door
		Envelope	Category	Cladding	Cladding
			Material	Bricks - modular	Bricks - modular
		2.1.2 - 0FL - Int - 4" conc blk - plaster (stair typ)			
		Window Opening	Wall Type	Interior	Interior
			Length (ft)	50	50
			Height (ft)	12	12
			Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
		2.1.3 - 0FL - Int - 4" conc blk (lab partition typ)			
		Window Opening	Wall Type	Interior	Interior
			Length (ft)	557	557
			Height (ft)	12	12
			Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	8	8
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.4 - 0FL - Int - 8" conc blk (corridor typ)			
			Wall Type	Interior	Interior
			Length (ft)	1250	1250

			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	24	24
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.5 - 1FL - Ext - 6" conc blk - 1" insul - brick (lab typ)			
			Wall Type	Exterior	Exterior
			Length (ft)	909	454.5
			Height (ft)	12	12
		Window Opening	Number of Windows	187	94
			Total Window Area (ft2)	1528	764
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
		2.1.6 - 1FL - Ext - plaster - 4" conc blk - 1" insul - brick (west facade)			
			Wall Type	Exterior	Exterior
			Length (ft)	144	144
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0

			Total Window Area (ft2)	0	0
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.7 - 1FL - Ext - plaster - 6" conc blk - 1" insul - brick (office typ)			
			Wall Type	Exterior	Exterior
			Length (ft)	444	444
			Height (ft)	12	12
		Window Opening	Number of Windows	77	77
			Total Window Area (ft2)	1177.4	1177.4
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding

			Material	Brick - modular	Brick - modular
		2.1.8 - 1FL - Int - 4" conc blk - 80% glz door			
			Wall Type	Interior	Interior
			Length (ft)	26	26
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	4	4
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		Envelope	Category	None	None
			Material	None	None
		2.1.9 - 1FL - Int - 4" conc blk - plaster (stair typ)			
			Wall Type	Interior	Interior
			Length (ft)	75	75
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
		2.1.10 - 1FL - Int - 4" conc blk (corridor typ)			
			Wall Type	Interior	Interior
			Length (ft)	739	739
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window	0	0

			Area (ft2)		
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	35	35
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.11 - 1FL - Int - 4" conc blk (lab partition typ)			
			Wall Type	Interior	Interior
			Length (ft)	1542	1542
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	18	18
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.12 - 1FL - Int - plaster - 4" conc blk - brick (west corridor)			
			Wall Type	Interior	Interior
			Length (ft)	283	283
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	13	13
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum

					regular 5/8"
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.13 - 1FL - Int - plaster - 4" conc blk - plaster (office/class partition typ)			
			Wall Type	Interior	Interior
			Length (ft)	408	408
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
		2.1.14 - 2FL - Ext - 6" conc blk - 1" insul - brick (lab typ)			
			Wall Type	Exterior	Exterior
			Length (ft)	746	248.67
			Height (ft)	12	12
		Window Opening	Number of Windows	202	68.00
			Total Window Area (ft2)	1920.3	640.1
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Insulation	Insulation
			Material	Polystyrene	Polystyrene

				extruded	extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.15 - 2FL - Ext - plaster - 6" conc blk - 1" insul - brick (office typ)			
			Wall Type	Exterior	Exterior
			Length (ft)	478	746
			Height (ft)	12	12
		Window Opening	Number of Windows	77	77
			Total Window Area (ft2)	1177.4	1920.3
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.16 - 2FL - Ext - plaster - 4" conc blk - 1" insul - brick (west facade)			
			Wall Type	Exterior	Exterior
			Length (ft)	231	231
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum

			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.17 - 2FL - Int - 4" conc blk - 80% glz door			
		Window Opening	Wall Type	Interior	Interior
			Length (ft)	26	26
			Height (ft)	12	12
			Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	4	4
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		Envelope	Category	None	None
			Material	None	None
		2.1.18 - 2FL - Int - 4" conc blk - plaster (stair typ)			
		Window Opening	Wall Type	Interior	Interior
			Length (ft)	76	76
			Height (ft)	12	12
			Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None

		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
		2.1.19 - 2FL - Int - 4" conc blk (corridor typ)			
			Wall Type	Interior	Interior
			Length (ft)	763	763
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	43	43
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.20 - 2FL - Int - 4" conc blk (lab partition typ)			
			Wall Type	Interior	Interior
			Length (ft)	1623	1623
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	29	29
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.21 - 2FL - Int - plaster - 4" conc blk - brick (west corridor)			
			Wall Type	Interior	Interior
			Length (ft)	263	263

		Window Opening	Height (ft)	12	12
			Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	9	9
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.22 - 2FL - Int - plaster - 4" conc blk - plaster (office/class partition typ)			
		Window Opening	Wall Type	Interior	Interior
			Length (ft)	623	623
			Height (ft)	12	12
			Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
		2.1.23 - 3FL - Ext - 6" conc blk - 1" insul - brick (lab typ)			
			Wall Type	Exterior	Exterior
			Length (ft)	746	373

			Height (ft)	12	12
		Window Opening	Number of Windows	135	68
			Total Window Area (ft2)	2019.7	1009.85
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.24 - 3FL - Ext - plaster - 6" conc blk - 1" insul - brick (office typ)			
			Wall Type	Exterior	Exterior
			Length (ft)	485	485
			Height (ft)	12	12
		Window Opening	Number of Windows	77	77
			Total Window Area (ft2)	1177.4	1177.4
			Fixed or Operable	Operable	Fixed
			Frame Type	Steel	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick -

					modular
		2.1.25 - 3FL - Int - 4" conc blk - 80% glz door			
			Wall Type	Interior	Interior
			Length (ft)	25	25
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	4	4
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		Envelope	Category	None	None
			Material	None	None
		2.1.26 - 3FL - Int - 4" conc blk - plaster (stair typ)			
			Wall Type	Interior	Interior
			Length (ft)	79	79
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	0	0
			Door Type	None	None
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
		2.1.27 - 3FL - Int - 4" conc blk (corridor typ)			
			Wall Type	Interior	Interior
			Length (ft)	772	772
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0

			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	37	37
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.28 - 3FL - Int - 4" conc blk (lab partition typ)			
			Wall Type	Interior	Interior
			Length (ft)	1490	1490
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	13	13
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	None	None
			Material	None	None
		2.1.29 - 3FL - Int - plaster - 4" conc blk - brick (west corridor)			
			Wall Type	Interior	Interior
			Length (ft)	280	280
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	6	6
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"

			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.1.30 - 3FL - Int - plaster - 4" conc blk - plaster (office/class partition typ)			
			Wall Type	Interior	Interior
			Length (ft)	468	468
			Height (ft)	12	12
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	4	4
			Door Type	Solid wood door	Solid wood door
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
	2.2 Cast in Place Wall				
		2.2.1 - 0FL - Ext - 8" cast - 1" insul - brick			
			Length (ft)	279	279
			Height (ft)	12	12
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
		Window Opening	Number of Windows	45	45
			Total Window Area (ft2)	787.4	787.4
			Fixed or Operable	Fixed	Fixed
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)

		Door Opening	Number of Doors	5	5
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		Envelope	Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.2 - 0FL - Ext - 8" cast - brick			
			Length (ft)	338	338
			Height (ft)	12	12
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
		Door Opening	Number of Doors	4	4
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		Envelope	Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.3 - 0FL - Ext - plaster - 1" insul - cast 8" (below grade)			
			Length (ft)	1255	1255
			Height (ft)	15	15
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
		Window Opening	Number of Windows	64	64
			Total Window Area (ft2)	741.1	741.1
			Fixed or Operable	Fixed	Fixed
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard (single pane)	Standard glazing (double pane)
		Door Opening	Number of Doors	4	4
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		Envelope	Category	Gypsum Board	Gypsum

					Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
		2.2.4 - 1FL - Ext - brick - 8" cast - brick			
		Envelope	Length (ft)	135	135
			Height (ft)	12	12
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.5 - 2FL - Ext - brick - 8" cast - brick			
		Envelope	Length (ft)	134	134
			Height (ft)	12	12
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.6 - 2FL - Int - 2" cast - brick (balcony long)			
		Envelope	Length (ft)	127	31.75
			Height (ft)	7.25	7.25
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	2	8
			Concrete flyash %	-	Average
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.7 - 2FL - Int - 2" cast - brick (balcony short)			
			Length (ft)	126	31.5
			Height (ft)	3.31	3.31

		Envelope	Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	2	8
			Concrete flyash %	-	Average
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.8 - 3FL - Ext - brick - 8" cast - brick			
		Envelope	Length (ft)	130	130
			Height (ft)	12	12
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
		2.2.9 - 3FL - Ext - plaster - 4" cast - 1" rigid insul - brick (library)			
			Length (ft)	225	112.5
			Height (ft)	18	18
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	4	8
			Concrete flyash %	-	Average
		Window Opening	Number of Windows	1	1
			Total Window Area (ft2)	91.1	91.1
			Fixed or Operable	Fixed	Fixed
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard (single pane)	Standard glazaing (double pane)
		Envelope	Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding

			Material	Brick - modular	Brick - modular
		2.2.10 - 0FL - Ext - 8" cast - 1" insul - brick (N loading area)			
			Length (ft)	70	70
			Height (ft)	12	12
			Concrete (psi)	3000	3000
			Rebar	#5	#5
			Thickness (in)	8	8
			Concrete flyash %	-	Average
		Window Opening	Number of Windows	0	0
			Total Window Area (ft2)	0	0
			Fixed or Operable	None	Fixed
			Frame Type	None	None
			Glazing Type	None	None
		Door Opening	Number of Doors	4	4
			Door Type	Steel exterior door	Steel exterior door
		Envelope	Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
			Category	Cladding	Cladding
			Material	Brick - modular	Brick - modular
	2.3 Curtain Wall				
		2.3.1 - 0FL - Int - curtain - 90% glz			
			Length (ft)	31	31
			Height (ft)	12	12
			Percent Viewable Glazing %	90	90
			Percent Spandrel Panel %	10	10
			Thickness of insulation (in)	0	0.0001
			Metal or Opaque Glass Spandrel	Metal	Metal
		Door Opening	Number of Doors	6	6
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		2.3.2 - 1FL - Int - curtain - 90% glz			
			Length (ft)	182	182

			Height (ft)	12	12
			Percent Viewable Glazing %	90	90
			Percent Spandrel Panel %	10	10
			Thickness of insulation (in)	0	0
			Metal or Opaque Glass Spandrel	Metal	Metal
		Door Opening	Number of Doors	22	22
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		2.3.3 - 2FL - Int - curtain - 90% glz			
			Length (ft)	203	203
			Height (ft)	12	12
			Percent Viewable Glazing %	90	90
			Percent Spandrel Panel %	10	10
			Thickness of insulation (in)	0	0
			Metal or Opaque Glass Spandrel	Metal	Metal
			Concrete flyash %	-	Average
		Door Opening	Number of Doors	7	7
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
		2.3.4 - 3FL - Int - curtain - 90% glz			
			Length (ft)	189	189
			Height (ft)	12	12
			Percent Viewable Glazing %	90	90
			Percent Spandrel Panel %	10	10
			Thickness of insulation (in)	0	0
			Metal or Opaque Glass Spandrel	Metal	Metal
		Door Opening	Number of Doors	13	13
			Door Type	Aluminum, 80% glazing	Aluminum, 80% glazing
3 Mixed Columns and Beams					
	3.1 Concrete Column and				

Concrete Beam				
	3.1.1 - 0FL Beams (E wing) & 0FL Beams (E wing)			
		Number of Beams	10	10
		Number of Columns	10	10
		Floor to floor height (ft)	13.5	13.5
		Bay sizes (ft)	11.7	11.7
		Supported span	20.5	20.5
		Live load (psf)	120	100
	3.1.2 - 0FL Columns (N & S wing) & 0FL Beams (N & S wing)			
		Number of Beams	48	48
		Number of Columns	13	13
		Floor to floor height (ft)	13.5	13.5
		Bay sizes (ft)	24.77	24.77
		Supported span	27	27
		Live load (psf)	120	100
	3.1.3 - 0FL Columns (W wing) & 0FL Beams (W wing)			
		Number of Beams	20	20
		Number of Columns	20	20
		Floor to floor height (ft)	13.5	13.5
		Bay sizes (ft)	8.85	10
		Supported span	21.5	21.5
		Live load (psf)	60	45
	3.1.4 - 1FL Columns (E wing) & 1FL Beams (E wing)			
		Number of Beams	16	16
		Number of Columns	10	10
		Floor to floor height (ft)	13	13
		Bay sizes (ft)	11.90	11.90
		Supported span	20.5	20.5
		Live load (psf)	120	100
	3.1.5 - 1FL Columns (N & S wing) & 1FL			

Beams (N & S wing)			
	Number of Beams	51	51
	Number of Columns	24	24
	Floor to floor height (ft)	13	13
	Bay sizes (ft)	13.42	13.42
	Supported span	27	27
	Live load (psf)	120	100
3.1.6 - 1FL Columns (W wing) & 1FL Beams (W wing)			
	Number of Beams	18	18
	Number of Columns	19	19
	Floor to floor height (ft)	13	13
	Bay sizes (ft)	9.37	10
	Supported span	21.5	21.5
	Live load (psf)	60	45
3.1.7 - 2FL Columns (E wing) & 2FL Beams (E wing)			
	Number of Beams	16	16
	Number of Columns	10	10
	Floor to floor height (ft)	13	13
	Bay sizes (ft)	11.8	11.8
	Supported span	20.5	20.5
	Live load (psf)	120	100
3.1.8 - 2FL Columns (N & S wing) & 2FL Beams (N & S wing)			
	Number of Beams	48	48
	Number of Columns	24	24
	Floor to floor height (ft)	13	13
	Bay sizes (ft)	13.42	13.42
	Supported span	27	27
	Live load (psf)	120	100
3.1.9 - 2FL Columns (W wing) & 2FL Beams (W wing)			
	Number of Beams	18	18
	Number of	19	19

			Columns		
			Floor to floor height (ft)	13	13
			Bay sizes (ft)	9.32	10
			Supported span	21.5	21.5
			Live load (psf)	120	100
		3.1.10 - 3FL Columns (E wing) & 3FL Beams (E wing)			
			Number of Beams	17	17
			Number of Columns	9	9
			Floor to floor height (ft)	13	13
			Bay sizes (ft)	10.56	10.56
			Supported span	20.5	20.5
			Live load (psf)	40	45
		3.1.11 - 3FL Columns (N & S wing) & 3FL Beams (N & S wing)			
			Number of Beams	44	44
			Number of Columns	24	24
			Floor to floor height (ft)	13	13
			Bay sizes (ft)	13.38	13.38
			Supported span	27	27
			Live load (psf)	40	45
		3.1.12 - 3FL Columns (W wing) & 3FL Beams (W wing)			
			Number of Beams	32	32
			Number of Columns	18	18
			Floor to floor height (ft)	17.5	17.5
			Bay sizes (ft)	9.33	10
			Supported span	21.5	21.5
			Live load (psf)	40	45
	3.2 WF Column and Beam				
		3.2.1 - Penthouse Columns WF & Penthouse Beams WF			
			Number of Beams	73	73
			Number of Columns	149	149

			Floor to floor height (ft)	6	6
			Bay sizes (ft)	5.85	10
			Supported span	14	14
			Live load (psf)	40	45
4 Roofs					
	4.1 Suspended Slab				
		4.1.1 - plaster - 4" Susp slab - cement top - 1" rigid insul (W wing)			
		Envelope	Roof Width (ft)	148	202.27
			Span (ft)	41	30
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Live load (psf)	40	45
			Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
		4.1.2 - plaster - 4" Susp slab - cement top - 1" rigid insul (E wing)			
		Envelope	Roof Width (ft)	148	202.27
			Span (ft)	41	30
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Live load (psf)	40	45
			Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
		4.1.3 - plaster - 4" Susp slab - cement top - 1" rigid insul (N & S wing)			
			Roof Width (ft)	364	667.33
			Span (ft)	55	30

		Envelope	Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Live load (psf)	40	45
			Category	Gypsum Board	Gypsum Board
			Material	Plaster 5/8"	Gypsum regular 5/8"
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
	4.2 Open Web Steel Joist				
		4.2.1 - Width - Penthouse - steel joist - metal decking - 1" rigid insul			
		Envelope	Roof Width (ft)	436	404.51
			Span (ft)	14	15.09
			Topping	Excluded	Excluded
			Live load (psf)	40	45
			Category	Steel Roof System	Steel Roof System
			Material	Commercial	Commercial
			Category	Insulation	Insulation
			Material	Polystyrene extruded	Polystyrene extruded
			Thickness (in)	1	1
5 Floors					
	5.1 Concrete Precast Double T				
		5.2.1 - 1,2,3 FL + roof - double T - cement top (E wing typ)			
			Number of bays	693	947
			Bay sizes (ft)	2	2
			Span (ft)	41	30
			Live load (psf)	120	100
			Topping	Included	Included
		5.2.2 - 1,2,3 FL + roof - double T - cement top (N & S wing typ)			
			Number of bays	2214	3985
			Bay sizes (ft)	2	2
			Span (ft)	54	30
			Live load (psf)	120	100

			Topping	Included	Included
		5.2.3 - Roof - double T - cement top (E wing)			
			Number of bays	231	316
			Bay sizes (ft)	2	2
			Span (ft)	41	30
			Live load (psf)	40	45
			Topping	Included	Included
		5.2.4 - Roof - double T - cement top (N & S wing)			
			Number of bays	738	1328
			Bay sizes (ft)	2	2
			Span (ft)	54	30
			Live load (psf)	40	45
			Topping	Included	Included
		5.2.5 - 1FL - double T - cement top (W wing)			
			Number of bays	389	635
			Bay sizes (ft)	2	2
			Span (ft)	49	30
			Live load (psf)	60	45
			Topping	Included	Included
		5.2.6 - 2FL - double T - cement top (W wing)			
			Number of bays	384	512
			Bay sizes (ft)	2	2
			Span (ft)	40	30
			Live load (psf)	60	45
			Topping	Included	Included
		5.2.7 - 3FL - double T - cement top (W wing)			
			Number of bays	368	613
			Bay sizes (ft)	2	2
			Span (ft)	50	30
			Live load (psf)	150	100
			Topping	Included	Included
		5.2.8 - Roof - double T - cement top (W wing)			
			Number of bays	53	87
			Bay sizes (ft)	2	2
			Span (ft)	49	30
			Live load (psf)	40	45
			Topping	Included	Included
6 Extra Basic					

Materials					
	6.1 Concrete				
		Total			
			20 MPa average flyash (m3)	130.17	130.17
			Mortar (m3)	8.63	7.18
		6.1.1 - Precast Concrete Cap for Pilaster Col'n 0,1,2,3FL Types A,B,H,M			
			20 MPa average flyash (m3)	20.26	20.26
		6.1.2 - Precast Concrete Cap linear			
			20 MPa average flyash (m3)	109.91	109.91
		6.2.1 - Penthouse brick wall length			
			Mortar (m3)	1.1	1.1
		6.2.2 - Pilaster Col'n 0,1,2,3FL Types A,B,H,M			
			Mortar (m3)	7.53	6.08
	6.2 Extra Materials - Cladding				
		Total			
			Modular brick (m2)	3393.47	3248.72
		6.3.1 - Penthouse brick wall length			
			Modular brick (m2)	498.51	498.51
		6.3.2- Pilaster Col'n 0,1,2,3FL Types A,B,H,M			
			Modular brick (m2)	2894.96	2750.21

APPENDIX B – INPUT ASSUMPTIONS

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Foundation	The concrete slab on grade (SOG) foundation at the floor of the ground level was modelled using the area condition. In the Impact Estimator (IE), there are two options for the SOG thickness: 4” or 8” thickness. In cases where the ideal rebar input was unavailable in the Impact Estimator, the next nearest option was selected and assumed for modelling purposes. The concrete flyash content was not specified in the drawings; it was assumed to be the average amount. Concrete is assumed to have a strength of 3000 psi for all cases unless otherwise noted, as specified. Also, the vapour barrier was assumed to be 6 mil, instead of 4 mil, as this was the only option in the IE. Concrete footings used to help form the building foundation were modelled using either the linear condition (e.g. strip/wall footings with specified cross-sectional dimensions) or the count condition (e.g. pad/column footings with specified dimensions). The IE limits the thickness of footings to 19.7". For footings thicker than this limit, the thickness was set to 19.7" and the width was increased accordingly to maintain equal volume. See drawings 386-07-009 and 386-07-010 for specifications of footing dimensions. The linear condition was used to model the concrete stairs as footings. After measuring an average stair thickness (assumed to be 10”) and width, the length of stairs was measured using a linear condition. The internal stairs have a 1” plaster topping which was omitted as the IE does not have an option to add a layer of plaster to concrete footings. The concrete columns inside the pilasters surrounding the exterior of the building are modelled as footings. The cross-sectional dimensions are specified (drawings 386-07-011 and drawings 386-07-013) and the lengths were measured using a linear condition. The pilaster columns contain various rebar sizes; #4 rebar was assumed to be the average. For all concrete footings, the flyash content was not specified in the drawings; it was assumed to be the average amount. Concrete is assumed to have a strength of 3000 psi for all cases unless otherwise noted, as specified.		
	1.1 Concrete Slab-on-Grade		
		1.1.1 - Slab 4" thick #3	The area of this slab was measured to be 35434 square feet. The following calculation determines the width input after arbitrarily selecting 100 feet as the length. = (35454 ft2) / (100 ft) = 354.34 ft
		1.1.2 - Slab 8" thick #4	The area of this slab was measured to be 934 square feet. The following calculation determines the width input after arbitrarily selecting 100 feet as the length. = (934 ft2) / (100 ft) = 9.34 ft
	1.2 Concrete Footing		
		1.2.9 - Ftg Linear 36" x 24"	The Impact Estimator limits the thickness of a footing to be a maximum of 19.7". The measured length was maintained and the thickness was set at 19.7". The following calculation determines the width input based on the same volume of concrete footing. = [length x width x thickness] / [length x (19.7"/12)] = [703' x 3' x (24"/12)] / [703' x (19.7"/12)]

			= 3.65 feet
		1.2.16 - Ftg Pad 4'6" x 5'2" 1'9" deep #5	The Impact Estimator limits the thickness of a footing to be a maximum of 19.7". The measured length was maintained and the thickness was set at 19.7". The following calculation determines the width input based on the same volume of concrete footing. = [length x width x thickness] / [length x (19.7"/12)] = [4.5' x (5+2/12)' x (21"/12)] / [4.5' x (19.7"/12)] = 5.51 feet
		1.2.20 - Ftg Pad 5'9" sq 1'9" deep #6	The Impact Estimator limits the thickness of a footing to be a maximum of 19.7". The measured length was maintained and the thickness was set at 19.7". The following calculation determines the width input based on the same volume of concrete footing. = [length x width x thickness] / [length x (19.7"/12)] = [5.75' x 5.75' x (24"/12)] / [5.75' x (19.7"/12)] = 7.01 feet
		1.2.21 - Ftg Pad 6'6" sq 2'0" deep #6	The Impact Estimator limits the thickness of a footing to be a maximum of 19.7". The measured length was maintained and the thickness was set at 19.7". The following calculation determines the width input based on the same volume of concrete footing. = [length x width x thickness] / [length x (19.7"/12)] = [6.5' x 6.5' x (24"/12)] / [6.5' x (19.7"/12)] = 7.92 feet
		1.2.22 - Ftg Pad 7'0" x 5'6" 1'10" deep #6	The Impact Estimator limits the thickness of a footing to be a maximum of 19.7". The measured length was maintained and the thickness was set at 19.7". The following calculation determines the width input based on the same volume of concrete footing. = [length x width x thickness] / [length x (19.7"/12)] = [7' x 5.5' x (22"/12)] / [7' x (19.7"/12)] = 6.14 feet

		1.2.23 - Ftg Pad 7'6" x 6'0" 2'0" deep #6	The Impact Estimator limits the thickness of a footing to be a maximum of 19.7". The measured length was maintained and the thickness was set at 19.7". The following calculation determines the width input based on the same volume of concrete footing. = [length x width x thickness] / [length x (19.7"/12)] = [7.6' x 6' x (24"/12)] / [7.6' x (19.7"/12)] = 7.31 feet
		1.2.24 - Stair #1,4 - #4 - 1" plaster topping	The concrete footing assembly group was used to model stairs because of its flexibility in adjusting thickness. The linear condition was used to measure the length after the width and average thickness was measured, also using a linear condition. Stairs #1 and #4 are identical. The following calculation calculates the length of both. = (number of stairs) x (length of stairs) = 2 x 138' = 276 feet The Impact Estimator does not have an option add a plaster topping to the concrete footing so the plaster topping was omitted.
		1.2.25 - Stair #2,3 - #4 - 1" plaster topping	The concrete footing assembly group was used to model stairs because of its flexibility in adjusting thickness. The linear condition was used to measure the length after the width and average thickness was measured, also using a linear condition. Stairs #2 and #3 are identical. The following calculation calculates the length of both. = (number of stairs) x (length of stairs) = 2 x 171' = 342 feet The Impact Estimator does not have an option add a plaster topping to the concrete footing so the plaster topping was omitted.
		1.2.26 - Stair ext - #4	The thickness of the external stairs were unspecified nor was there a clear cross-sectional view of the stairs. The thickness was assumed to be the same as those of other stairs (10"). The #4 rebar was also assumed as it was unspecified.

		1.2.27 - Pilaster Col'n 0FL Type A 1'0" x 1'7"	The following calculation determines the length input for all Type A pilasters modelled as a concrete footing. = (height of one pilaster) x (number of Type A pilasters) = 50' x 30 = 1500 feet
		1.2.28 - Pilaster Col'n 0FL Type B 1'0" x 1'9"	The following calculation determines the length input for all Type B pilasters modelled as a concrete footing. = (height of one pilaster) x (number of Type B pilasters) = 50' x 62 = 3100 feet
		1.2.29 - Pilaster Col'n 0FL Type C 1'0" x 1'9"	The following calculation determines the length input for all Type C pilasters modelled as a concrete footing. = (height of one pilaster) x (number of Type C pilasters) = 39' x 6 = 234 feet
		1.2.30 - Pilaster Col'n 0FL Type D 1'0" x 1'7" #7Vert	The following calculation determines the length input for all Type D pilasters modelled as a concrete footing. = (height of one pilaster) x (number of Type D pilasters) = 39' x 17 = 663 feet
		1.2.31 - Pilaster Col'n 1,2,3FL Type H 1'2.5" x 8" #5Vert	The following calculation determines the length input for all Type H pilasters modelled as a concrete footing. = (height of one pilaster) x (number of Type H pilasters) = 43' x 33 = 1419 feet

		1.2.32 - Pilaster Col'n 1,2,3FL Type M 1'11" x 1'1.5" #5Vert	The following calculation determines the length input for all Type H pilasters modelled as a concrete footing. = (height of one pilaster) x (number of Type H pilasters) = 30' x 17 = 510 feet
2 Custom Wall	The majority of walls in the H.R. MacMillan building are concrete block walls. They were modelled using the linear condition for distances. The linear condition was also used to measure the wall height and it was found to be 12’. This value is used as an assumption for the heights of all walls. A different category was used to measure walls depending on the type of wall construction. Some walls have 1” rigid insulation (assumed to be 1” extruded polystyrene), modular brick cladding, or plaster finish, or a combination of these elements. A different category was also used for walls with differing openings, such as solid wood doors, glazed steel doors, or window openings. In the IE, concrete block walls are assumed to use 8” x 8” x 16” hollow concrete blocks with every third vertical core grouted and reinforced with one steel bar (assumed to be #4), and additional grouting and rebar is included at all openings. These conditions are assumed for all concrete block walls in MacMillan. For all instances where walls had a plaster finish, it was assumed to be regular 5/8” thick gypsum board (plaster is not available as an option in the IE). Even though operable windows is an option in the IE, all windows are considered fixed for conformity to the rest of the LCA studies conducted on other UBC buildings. Steel window frames are also assumed to be aluminum frames in the IE as there is no option for steel. All doors made from wood, including those that are glazed, are assumed to be solid wooden doors, as there are no options for partially glazed wooden doors in the IE. Glazed aluminum doors were assumed to be 80% glazed. Some of the walls of the ground floor are cast in place concrete walls. They were measured using the linear condition. Similar to concrete block walls, different categories were used to perform takeoffs depending on the wall construction and wall openings. All the same assumptions were made. Note that bituminous waterproof compound was omitted as it is not available in the IE. Glazed curtain walls occur most often at the doorways to external and internal stairs. They are also modelled using the linear condition. It was assumed that the curtain walls had 90% viewable glazing and 10% opaque metal spandrel. The IE also requires a positive input for thickness of insulation. Since there was no insulation, this was assumed to be 0.0001. All the glazed metal doors were assumed to be 80% glazed aluminum doors.		
	2.1 Concrete Block Wall		
		2.1.3 - 0FL - Int - 4" conc blk (lab partition typ)	The wall layout drawings for the north side of the ground floors were unavailable. Thus the walls on the north side were estimated based on a physical site visit. The total length for this type of wall is 557' is based on a known length of 486' measured from drawings for the south side and an estimated length of 71' for the north side.

		2.1.4 - 0FL - Int - 8" conc blk (corridor typ)	The wall layout drawings for the north side of the ground floors were unavailable. Thus the walls on the north side were estimated based on a physical site visit. The total length for this type of wall is 1250' is based on a known length of 510' measured from drawings for the south side and an estimated length of 740' for the north side.
		2.1.5 - 1FL - Ext - 6" conc blk - 1" insul - brick (lab typ)	The Impact Estimator limits the door or window openings to a maximum of 100. In such cases, the total length of the wall, the number of window openings, and the window area are divided by 2 or 3, to decrease the number of openings (door or window) to less than 100. Then the assembly can be duplicated 2 or 3 times, accordingly, in the Impact Estimator. The following calculation determines the length and number of windows input. = total length of wall / 2 = 909' / 2 = 454.5 feet = number of windows / 2 = 187 / 2 = 94 = total window area / 2 = 1528 ft2 / 2 = 764 square feet The assembly was duplicated one time.
		2.1.14 - 2FL - Ext - 6" conc blk - 1" insul - brick (lab typ)	The Impact Estimator limits the door or window openings to a maximum of 100. In such cases, the total length of the wall, the number of window openings, and the window area are divided by 2 or 3, to decrease the number of openings (door or window) to less than 100. Then the assembly can be duplicated 2 or 3 times, accordingly, in the Impact Estimator. The following calculation determines the length and number of windows input. = total length of wall / 3 = 746' / 3 = 248.67 feet = number of windows / 3 = 202 / 3 = 68 = total window area / 3 = 1920.3 ft2 / 3 = 640.1 square feet The assembly was duplicated two times.

		2.1.23 - 3FL - Ext - 6" conc blk - 1" insul - brick (lab typ)	The Impact Estimator limits the door or window openings to a maximum of 100. In such cases, the total length of the wall, the number of window openings, and the window area are divided by 2 or 3, to decrease the number of openings (door or window) to less than 100. Then the assembly can be duplicated 2 or 3 times, accordingly, in the Impact Estimator. The following calculation determines the length and number of windows input. = total length of wall / 2 = 746' / 2 = 373 feet = number of windows / 2 = 135 / 2 = 68 = total window area / 2 = 2019.7 ft2 / 2 = 1009.85 square feet The assembly was duplicated one time.
		2.2.6 - 2FL - Int - 2" cast - brick (balcony long)	The Impact Estimator has two options for the thickness of a cast in place wall: 8" or 12". This 4" cast balcony wall on the 2nd floor has brick on both sides but up to different heights. The measured height was maintained and the thickness was set to 8". The following calculation determines the length input based on the same volume. = [length x width x thickness] / [length x (8"/12)] = [127.5 x 7.25' x (2"/12)] / [7.25' x (8"/12)] = 31.75 feet
		2.2.7 - 2FL - Int - 2" cast - brick (balcony short)	The Impact Estimator has two options for the thickness of a cast in place wall: 8" or 12". This 4" cast balcony wall on the 2nd floor has brick on both sides but up to different heights. The measured height was maintained and the thickness was set to 8". The following calculation determines the length input based on the same volume. = [length x width x thickness] / [length x (8"/12)] = [126 x 3.31' x (2"/12)] / [3.31" x (8"/12)] = 31.5 feet

3 Mixed Columns and Beams	Concrete columns and beams support the floors in H.R. MacMillan. The linear and count conditions were used to measure these elements. The count condition was used to measure the number of columns and beams. The linear condition was used to measure the floor to floor height. The bay size measurement was obtained by using the linear condition to measure the total distance between a series of columns, then dividing that by the number of columns to produce the average bay size. The IE requires that the bay size be 10’ or greater. The bay size was assumed to be 10’ in cases where the average bay size was less than 10’. The supported span was obtained by using the linear condition to measure the total span, then dividing that by two to produce the average span. The total span was divided by two since the floors are supported at each external wall, and in between by one series of columns. In the IE, three options are available for the live load: 45 psf, 75 psf, and 100 psf. None of the specified live loads matched these options so the closest options were assumed. For labs and offices, 100 psf was used instead of the specified 120 psf (labs) and 50 psf (offices) for a conservative assumption. For classrooms, 45 psf was used instead of the specified 60 psf since 100 psf was an overestimation for labs and offices; this creates a more balanced overall estimate. For the third floor columns supporting the roof, 45 psf was used for the specified snow load of 40 psf. Note that the size of the columns and beams are not considered by the IE. Steel wide flange columns and beams are used for the ‘penthouse’, which acts as a protective housing for the exhaust ducts from the labs. Similar to concrete columns and beams, the count condition was used to measure the number of columns and beams, and the linear condition was used to measure the floor to floor height. The same technique was used to obtain the average bay size. The calculated average bay size was 5.85’ but it is assumed to be 10’ due to this limitation in the IE.		
	3.1 Concrete Column and Concrete Beam		
		3.1.1 - 0FL Beams (E wing) & 0FL Beams (E wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 117' / 10 = 11.7 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 41' / 2 = 20.5 feet

		3.1.2 - 0FL Columns (N & S wing) & 0FL Beams (N & S wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 322' / 13 = 24.77 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 54' / 2 = 27 feet
		3.1.3 - 0FL Columns (W wing) & 0FL Beams (W wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 177' / 20 = 8.85 feet --> 10 feet The Impact Estimator requires the bay size to be a minimum of 10'. In cases where the bay size is less than 10', it is assumed to be 10'. The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 43' / 2 = 21.5 feet

		3.1.4 - 1FL Columns (E wing) & 1FL Beams (E wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 119' / 10 = 11.9 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 41' / 2 = 20.5 feet
		3.1.5 - 1FL Columns (N & S wing) & 1FL Beams (N & S wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 322' / 24 = 13.42 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 54' / 2 = 27 feet

		3.1.6 - 1FL Columns (W wing) & 1FL Beams (W wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 178' / 19 = 9.37 feet --> 10 feet The Impact Estimator requires the bay size to be a minimum of 10'. In cases where the bay size is less than 10', it is assumed to be 10'. The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 43' / 2 = 21.5 feet
		3.1.7 - 2FL Columns (E wing) & 2FL Beams (E wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 118' / 10 = 11.8 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 41' / 2 = 20.5 feet

		3.1.8 - 2FL Columns (N & S wing) & 2FL Beams (N & S wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 322' / 24 = 13.42 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 54' / 2 = 27 feet
		3.1.9 - 2FL Columns (W wing) & 2FL Beams (W wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 177' / 19 = 9.32 feet --> 10 feet The Impact Estimator requires the bay size to be a minimum of 10'. In cases where the bay size is less than 10', it is assumed to be 10'. The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 43' / 2 = 21.5 feet

		3.1.10 - 3FL Columns (E wing) & 3FL Beams (E wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 95' / 9 = 10.56 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 41' / 2 = 20.5 feet
		3.1.11 - 3FL Columns (N & S wing) & 3FL Beams (N & S wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 321' / 24 = 13.38 feet The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 54' / 2 = 27 feet

		3.1.12 - 3FL Columns (W wing) & 3FL Beams (W wing)	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 168' / 18 = 9.33 feet --> 10 feet The Impact Estimator requires the bay size to be a minimum of 10'. In cases where the bay size is less than 10', it is assumed to be 10'. The following calculation determines the span size input based on the measured total span and two sides that the column supports. = (measured total span size) / 2 = 43' / 2 = 21.5 feet
	3.2 WF Column and Beam		
		3.2.1 - Penthouse Columns WF & Penthouse Beams WF	The bay size was calculated by measuring the total distance of a series of columns then dividing that by the number of columns for the average bay size. The following calculation determines the bay size input based on the measured total bay size and the number of columns. = (measured total bay size) / (number of columns) = 2 x 436' / 149 = 5.85 feet --> 10 feet The Impact Estimator requires the bay size to be a minimum of 10'. In cases where the bay size is less than 10', it is assumed to be 10'.
4 Roofs	A suspended slab roof is used for the H.R. MacMillan building. The linear condition was used to measure the width and spans of the roof. The IE requires the span input to be 30'. Thus for instances where the span is greater than 30', the span is set to 30' and the width is adjusted accordingly to maintain the same area. The live load was assumed to be 45 psi, the nearest option to the specified 40 psf snow load. The plaster finish was assumed to be regular 5/8" gypsum board as plaster is not available as an option in the IE. The 1" rigid insulation was assumed to be 1" extruded polystyrene. The flyash content was not specified in the drawings; it was assumed to be the average amount. Concrete is assumed to have a strength of 3000 psi for all cases unless otherwise noted, as specified. The roof of the 'penthouse' was assumed to be an open web steel joist roof. Similar to the suspended slab roof, the width and span was measured using the linear condition. In the IE, the span requires a minimum of 15.09'. The span was set to 15.09' and the width was adjusted accordingly to maintain the same area. It		

	was assumed to be a commercial steel roof system.		
	4.1 Suspended Slab		
		4.1.1 - plaster - 4" Susp slab - cement top - 1'' rigid insul (W wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the width input based on setting the span to 30' and to maintain the same area. = (measured length) x (measured span) / 30' = 148' x 41' / 30' = 202.27 feet
		4.1.2 - plaster - 4" Susp slab - cement top - 1'' rigid insul (E wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the width input based on setting the span to 30' and to maintain the same area. = (measured length) x (measured span) / 30' = 148' x 41' / 30' = 202.27 feet
		4.1.3 - plaster - 4" Susp slab - cement top - 1'' rigid insul (N & S wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the width input based on setting the span to 30' and to maintain the same area. = (measured length) x (measured span) / 30' = 364' x 55' / 30' = 667.33 feet
	4.2 Open Web Steel Joist		
		4.2.1 - Width - Penthouse - steel joist - metal decking - 1" rigid insul	In the Impact Estimator, the span is limited to a minimum of 15.09'. The following calculation determines the width input based on setting the span to 15.09' and to maintain the same area. = (measured length) x (measured span) / 15.09' = 436' x 14' / 15.09' = 404.51 feet The commercial steel roof system was the nearest option to the actual steel roof assembly.
5 Floors	Concrete precast tees are used for the flooring system. Although the precast tees in the H.R. MacMillan building are single and not double tees, this was assumed to be the case as it is the closest option. The count and linear condition was used to take measurements. The count condition was used to measure the number of bays and the linear condition was used to measure the bay size and the span size. The technique used to measure span size was the same as that used in concrete columns and beams. Due the		

	span size being limited to 30’, the span was set to 30’ and the number of bays was adjusted accordingly to produce the equivalent floor size. The live load assumptions were the same as that used in concrete columns and beams.		
	5.1 Concrete Precast Double T		
		5.2.1 - 1,2,3 FL + roof - double T - cement top (E wing typ)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. It is also multiplied by 3 for 3 repeated floors. = (number of floors) x (number of bays) x (measured span) / 30' = 3 x 231 x 41' / 30' = 947 bays
		5.2.2 - 1,2,3 FL + roof - double T - cement top (N & S wing typ)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. It is also multiplied by 2 for the north and side sides, and by 3 for 3 repeated floors. = (number of sides) x (number of floors) x (number of bays) x (measured span) / 30' = 2 x 3 x 369 x 54' / 30' = 3985 bays
		5.2.3 - Roof - double T - cement top (E wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. = (number of bays) x (measured span) / 30' = 231 x 41' / 30' = 316 bays
		5.2.4 - Roof - double T - cement top (N & S wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. It is also multiplied by 2 for the north and side sides. = (number of sides) x (number of bays) x (measured span) / 30' = 2 x 369 x 54' / 30' = 1328 bays

		5.2.5 - 1FL - double T - cement top (W wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. = (number of bays) x (measured span) / 30' = 389 x 49' / 30' = 635 bays
		5.2.6 - 2FL - double T - cement top (W wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. = (number of bays) x (measured span) / 30' = 384 x 40' / 30' = 512 bays
		5.2.7 - 3FL - double T - cement top (W wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. = (number of bays) x (measured span) / 30' = 368 x 50' / 30' = 613 bays
		5.2.8 - Roof - double T - cement top (W wing)	In the Impact Estimator, the span is limited to a maximum of 30'. The following calculation determines the number of bays input based on setting the span to 30' and to maintain the same area. = (number of bays) x (measured span) / 30' = 53 x 49' / 30' = 87 bays
6 Extra Basic Materials	In the Impact Estimator, additional materials can be entered manually to account for any components that are not covered by the default assembly groups. For the H.R. MacMillan building, this section was used to add concrete (20 MPa = 3000 psi) for the precast concrete caps that are on top of the pilasters and that surround the exterior edge at the roof. Modular brick was added for the penthouse walls and for the pilasters. Finally, mortar was added for the penthouse brick walls and the brick cladding on the pilasters.		
	6.1 Concrete		
		6.1.1 - Precast Concrete Cap for Pilaster Col'n 0,1,2,3FL Types A,B,H,M	The number of precast concrete caps for the pilasters were 30 + 62 + 33 + 17 = 161; each number corresponds to the number of each type of pilasters A, B, H, and M. The length, width, and height dimensions were specified so the total volume of concrete is determined by the following calculation. It was assumed to be 20 MPa = 3000 psi concrete. = (number of concrete caps) x (height) x (width) x (volume) = 161 x 3.33' x 1' x 1.33' = 715.56 ft3

			= 20.26 m3
		6.1.2 - Precast Concrete Cap linear	The linear condition was used to measure the total distance that the strip concrete caps covered the exterior edge of the roof. The cross-sectional dimensions were specified. The total volume of the concrete is determined by the following calculation. It was assumed to be 20 MPa = 3000 psi concrete. = (measured distance) x (height) x (width) = 2911' x 1.33' x 1' = 3881.33 ft3 = 109.91 m3
		6.2.1 - Penthouse brick wall length	The mortar for the penthouse brick wall was determined by first determining the amount of mortar associated with one square meter of brick wall. Linear conditions were used to measure the length and height of the brick wall. The following calculation determines the amount mortar used for the penthouse brick wall. = (wall length) x (wall height) = wall area = 897' x 6' = 5382 sf = 498.51 m2 = (wall area) x (mortar per wall area) = 498.51 m2 x 0.00221 m3/m2 = 1.10 m3

		6.2.2 - Pilaster Col'n 0,1,2,3FL Types A,B,H,M	The mortar for the brick on the pilasters wall was determined by first determining the amount of mortar associated with one square meter of brick wall. Linear conditions were used to measure the length and width of the pilasters to obtain the brick area. This was multiplied by the number of pilasters to determine the total brick area. The following table determines the amount mortar used for the pilaster bricks.

Column type	avg height (ft)	length (ft)	width (ft)
A	50	1	1
B	50	1	1
C	39	1	1
D	39	1	1
H	43	1.21	0
M	30	1.13	1

	6.2 Extra Materials - Cladding		
		6.3.1 - Penthouse brick wall length	The brick for the penthouse walls was obtained by first measuring the length and height of the walls using a linear condition. The following calcuation determines the area of brick wall. = (length of wall) x (height of wall) = 897' x 6' = 5382 ft2 = 498.51 m2
		6.3.2- Pilaster Col'n 0,1,2,3FL Types A,B,H,M	The brick for the pilasters was calculated by first using linear conditions to measure the length and width of the pilasters. Then the areas for each pilasters were multiplied by the number of pilasters. See the above table for the detailed calculation.