Life Cycle Analysis Study of the EOS Main Building at the University of British Columbia

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PROVISO

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

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

LIFE CYCLE ANALYSIS STUDY OF THE EOS MAIN BUILDING AT THE UNIVERSITY OF BRITISH COLUMBIA

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ABSTRACT

This report is the result of a Life Cycle Assessment (LCA) study on the EOS Main building at the University of British Columbia. It encompasses a cradle-to-gate scope that includes the raw material extraction, manufacturing of construction materials, and construction of the structure and envelope of the EOS Main building, as well as associated transportation effects throughout. The building is modeled in two different computer programs which are used to measure and quantify the materials consumed and their impact on the environment. The resulting summary measures table by life cycle stage is then used for sensitivity analysis and building performance. Sensitivity analysis on five selected building materials showed how the building's overall impact on the environment changed as the quantity of those materials increased by 10%. It was found that wide flange steel sections made an impact of 4% on the overall primary energy use and concrete (20 MPa) made an impact of 3.9% on the overall Ozone depletion potential. The two main environmental impacts of the building were found to be the primary energy consumption and weighted resource use with values estimated at 270 MJ/sqf. and 75.7 Kg/sqft respectively. Lastly, the building performance model showed how an "improved" EOS Main building would outperform the current building in terms of energy and heat loss. The pay-back period of the "improved" building was calculated to be one and a half years.

INTRODUCTION

The Earth and Ocean Sciences (EOS) Main building is located at 6339 Stores road on the UBC Vancouver campus. The building can be found on the corner of Education Rd. and Stores Rd. and its main entrance is on the east side of the building located on Education Rd. EOS Main was designed by McCarter, Nairne and Partners in 1970 and was originally named the Geological Science Center. The building is three stories tall and it is the first building at UBC constructed with a structure of light steel framing. Due to limited budgeting, construction was done by 1971 with a total cost of $2.83 million; modifications were done later in 1973.

The structural materials used were concrete and steel; concrete was mainly used in the foundations, slab on grade, basement walls and basement columns while steel was used in the upper floors as hollow steel structure (HSS) columns and open web steel joists (OWSJ) in the floors and roof system. The building's exterior appearance is a mixture of ivory-coloured aluminum panels with low emissivity tin glazed windows of one story height.

EOS Main serves as an educational and institutional building with space designated to twenty classrooms, eighteen laboratories, thirty six research and preparation rooms, eleven mechanical and electrical rooms, ten office spaces along with one library and one administration's office.

TABLE 1 - BUILDING CHARACTERISTICS

Building System	Specific Building Characteristics
Structure	Concrete and Steel. Basement: concrete columns and concrete block walls; first, second and third floor: HSS columns with OWSJ and aluminum cladding.
Floors	Basement: Concrete slab on grade with polyethylene (6mil) as vapour barrier; first, second, and third floors: open web steel joists with concrete cover
Exterior Walls	Basement: sand blasted concrete blocks with 2" fibreglass batt insulation, Polyethylene (6mil), and drywall finish with latex water based paint. First, second, and third floors: steel studs and aluminum cladding with 2" fibreglass batt insulation, Polyethylene (6mil), drywall finish and latex water based paint.
Interior Walls	Basement: concrete block; first, second, and third floors: steel studs with gypsum board and latex paint on both sides.
Windows	First, second and third floor windows have glazing (low E tin), double pane, and basement windows have standard glazing, single pane.
Roof	The roof envelope is commercial steel; open web steel joists, overlain by concrete cover; 2" rigid insulation (expanded polystyrene) and Polyethylene 6mil as vapour barrier.

GOAL AND SCOPE

GOAL OF STUDY

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

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

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

SCOPE OF STUDY

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

TOOLS, METHODOLOGY AND DATA

Two main software tools are to be utilized to complete this LCA study; OnCenter's OnScreen TakeOff (OST) and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings.

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

Using the formatted takeoff data, version 4.0.64 of the IE software, the only available software capable of meeting the requirements of this study, is used to generate a whole building LCA model for the EOS Main building in the Vancouver region as an Institutional building type. The IE software is designed to aid the building community in making more environmentally conscious material and design choices. The tool achieves this by applying a set of algorithms to the inputted takeoff data in order to complete the takeoff process and generate a bill of materials (BoM). This BoM then utilizes the Athena Life Cycle Inventory (LCI) Database, version 4.6, in order to generate a cradle-to-grave LCI profile for the building. In this study, LCI profile results focus on the manufacturing (inclusive of raw material extraction), transportation of construction materials to site and their installation as structure and envelope assemblies of the EOS Main building. As this study is a cradle-to-gate assessment, the expected service life of the EOS Main building is set to 1 year, which results in the maintenance, operating energy and end-of-life stages of the building's life cycle being left outside the scope of assessment.

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

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

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

The primary sources of data used in modeling the structure and envelope of the EOS Main building are the original architectural and structural drawings from when the building was initially constructed in 1970. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as their associated envelope and/or openings (ie. doors and windows). The decision to omit other building components, such as flooring, electrical aspects, HVAC system, finishing and detailing, etc., are associated with the limitations of available data and the IE software, as well as to minimize the uncertainty of the model. In the analysis of these assemblies, some of the drawings lack sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in the IE software. Furthermore, there are inherent assumptions made by the IE software in order to generate the bill of materials and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further as they emerge in the Building Model section of this report and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Annex B.

BUILDING MODEL

TAKEOFFS

As noted in the scope of the study, takeoffs were done in OST using the imported digital architectural and structural building drawings. In OST drawing scales were set according to original drawings and all relevant structural components and assembly groups were counted and measured. OST includes area, linear and count conditions for completing takeoffs. Each condition requires a set of inputs regarding the type of assembly being measured; inputs such as height, thickness, and depth. In addition to measuring and counting building components any relevant information about the component itself gathered from elsewhere was also recorded in OST. The software then uses the measured quantities to produce a takeoff list. For the purpose of this study the takeoff list produced by OST was the main source of input used in Athena Impact Estimator.

The takeoffs were generated based on the data obtained from different sources. The majority of the data was obtained from the original architectural and structural drawings provided by the UBC Records Section Office. The challenges of completing takeoffs were generally associated with the process of gathering data. The building design drawings, produced in 1970, were done by hand which made it difficult to extract information; most values were readable but some handwritten details were hard to read, therefore, reasonable assumptions were made when needed. The drawings lacked information about the materials used in the building and assumptions were made by inputting materials that were commonly used at the time of construction. A note was made every time a value was assumed during takeoffs. The renovation drawings from of 1983 and 1985 received from the Records Section, which were in better condition, were also used to extract some details about the wall assembly and floor plans. Visiting the site also helped in gathering information about the wall assembly, including the type of windows and doors.

Since LCA projects can be very large in scope and have great amounts of detail it is necessary to keep the information in such a way so that it is possible to find and modify data later, if necessary. To do this, it was essential to keep all information consistent with an assigned nomenclature. Not only this method kept the information organized and easy to follow, but it also made it easier to find and reference different components at different stages during the process. The benefits of having a well defined nomenclature became more evident when inputting the data into Athena IE.

Modeling and Assumptions

To model the building in Athena IE, assembly groups were created and building components fell into five major categories including: foundation, walls, columns and beams, floors, and roof. The choices for assembly groups and the building components associated with them were made to accommodate the Impact Estimator's input options.

Foundations

The foundations assembly group contains three components of the building structure; the slab on grade, stairs, and building footings. The basement and part of the first floor in EOS Main have a 5” thick slab on grade which was modeled in the Impact Estimator as a 4” thick slab due to limited input values in IE. Therefore the area of the slab was modified to make up for the lost concrete volume. The calculations and reasoning are shown in Annex B.

EOS Main building has four sets of stairs, two of which extend from the ground floor to the roof (1.2.14 and 1.2.15), one which extends from the basement to the roof (1.2.16), and one which extends from the basement to the ground floor (1.2.17). The four sets of stairs were modeled as foundation assemblies individually. The inclined length of the stairways was used as input length. The width and thickness of the stairways were read from the drawings and input into IE. The exterior stairways are shown on the North-South and East-West Elevation drawings and the core stairway is shown on the Section drawing in OST.

Foundation footings of EOS Main were assumed to be at the same elevations even though it was shown in the structural drawing 402-07-001 that they have slightly varying elevations. The thickness, width and length of each footing were provided in the structural drawing 402-07-008. In most cases, the footings had a thickness of larger than 19.7 inches which is the limit in the Impact Estimator. This limit affected the amount of concrete and rebar used in each footing and to accommodate it, the width of the footing was recalculated in order to avoid material loss and keep the volume consistent. The methodology for the calculation is shown in Annex B. All footings contained rebar types which were implemented in IE but one footing type (1.2.3) had rebar #7 which was not one of the provided options for rebar type in IE; rebar #6 was selected to match IE’s inputs.

WALLS

The walls in EOS Main building were either concrete blocks (2.1.1 – 2.1.2), cast in place (2.2.1) or steel studs (2.3.1 – 2.3.5). Wall assemblies were modeled in IE as exterior or interior walls.

Concrete block walls were used in the basement as both exterior and interior load bearing walls, but due to different envelope materials, they were modeled separately. Concrete blocks in the Impact Estimator are only the standard size of 8”x8” thick. Hence, the exterior wall which is composed of 10” thick concrete blocks was modeled as 8” thick blocks in IE. The internal wall’s concrete blocks match IE’s input of 8” thick. The exterior wall envelope was modeled similar to the specifications on the drawing 402-06-014 with 2” fiberglass batt insulations and polyethylene 6mil. The paint was assumed to be latex water based and the finishing was selected as regular gypsum wallboard instead of the drywall used, due to IE’s limited choices. External concrete block walls are shown in drawing 402-06-009 to have sandblasted concrete finish which is a finishing selected to improve the appearance of the wall. Impact Estimator does not have sandblasted concrete finish available therefore, no surface finish was selected for the external concrete walls.

Cast in place walls were used in the core stairwell located in the center of the EOS Main building. The length and width of the walls were measured in OST and inputted in IE with a thickness of 12”. Rebar was selected as #5 in IE because it was the closest to the actual rebar #4 used in the walls. The openings in the wall were wood doors with glass which were modeled as hollow core wood doors to match Athena’s inputs. Both of these assumptions have been shown in the Annex A.

The drawings lacked details regarding the size and spacing of the steel stud walls, therefore, reasonable assumptions were made when modeling steel stud walls (2.3.1 – 2.3.5) in the Impact Estimator. Stud spacing was measured in OST to be 20ft. and was modeled in IE as 24o.c. to match the inputs available. The drawings had no information regarding the stud weight and for the exterior and interior walls the weighting was assumed to be heavy (20 Ga) and light (25 Ga) respectively. Assumptions also had to be made for stud thickness; studs were assumed to be 1 5/8” x 8” thick for exterior walls and 1 5/8” x 6” thick for internal walls. The wall envelope of exterior walls was similar to concrete block walls. The finishing and paint were counted twice in Athena IE for interior walls since they were used on both sides. The exterior cladding of the building on the three topmost floors are modeled as commercial steel cladding instead of aluminum panels to match Athena Impact Estimator's inputs. The internal steel stud wall (2.3.4) contains fire-rated drywall and it is modeled as having fire-rated gypsum board type X (1/2") in Athena Impact Estimator.

COLUMNS AND BEAMS

When modeling the building in Athena Impact Estimator columns and beams were represented together. EOS Main has both concrete (3.1.1) and steel HSS (3.2.1 – 3.2.3) columns. The steel columns were all HSS 8x8x375 but the concrete columns varied in shape and size. The most common type of concrete column was used to model the basement floor (since different column thicknesses affect span and bay size). The columns and beams were counted and the bay size and span were measured in OST. The bay sizes of all floors in EOS Main were larger than IE's limit of 40ft. As shown in Annex B, the width and length of floors were recalculated with respect to the area and the bay size was modified to 40ft, increasing the original span size.

FLOORS

EOS Main has three types of floors; the basement and part of the first floor have concrete slab on grades (which have been accounted for in the foundation assembly group), the remaining part of the first floor has concrete suspended slab (4.1.1) and all other floors have open web steel joists (OWSJ) with concrete covers (4.2.1 and 4.2.2). The span size of first floor was measured by OST on drawing 402-07-002; the span size was the same for both the second and third floors and was measured on the structural drawing 402-07-003. The width of floors was calculated by dividing the floor area by the span size and the calculated value was inputted in the Impact Estimator. The live load of floors was not indicated on any of the structural drawing, therefore, it was assumed to be 75psf for all floors.

Roof

The roof was modeled as commercial steel roof with open web steel joists (OWSJ) and concrete topping. The roof plan is shown in structural drawing 402-07-005. The area and span size were the same as second and third floors; the floor width was found by performing calculations similar to the floors' calculations. The concrete used as topping was assumed to have a strength of 4000psf instead of the indicated value of 3500psf to match IE's inputs. Live load of roof was also assumed to be 75psf.

A recurring assumption made in the process of completing the LCA study on EOS Main was the percentage of flyash used in the concrete mix. The flyash used for all concrete assemblies is assumed to be average since no detail regarding the concrete mix was found. Assumptions were also made regarding the rebar type. The rebar used in concrete assemblies were shown on drawings 402-07-007, 402-07-008 and 402-07-010 and some assemblies contained more than one type of rebar, or used one that was not available in IE, therefore, an assumption was made and one rebar type was selected. There have been notes made in the IE_Inputs_Assumptions_Document (Annex B) every time a surrogate was used.

LCA studies are generally done on products which have service lives of many years. A report that is generated today may be used later on by someone else to expand the study, thus, all data and calculations must be as transparent and clear as possible. In order to do this, IE_Inputs_Document (Annex A) and IE_Inputs_Assumptions_Document (Annex B) were used to keep track of the data and show any changes or assumptions made to accommodate Athena's limitations. IE_Inputs_Assumptions_Document provides the specific details of the assumptions and the reasoning for making that assumption; it also shows the calculation and methodology used to get the input values. The assigned nomenclature was respected in all documents related to this LCA study.

BILL OF MATERIALS

After completing the building model and inputting all information about the assembly groups, Athena Impact Estimator generated a bill of materials (BoM) for the manufacturing and construction of the EOS Main building. Table 2 shows the generated BoM needed to manufacture and construct the building. As shown on the table different materials are counted with different metric units.

TABLE 2 - BILL OF MATERIALS

Material	Quantity	SI Unit
1/2" Fire-Rated Type X Gypsum Board	190.4066	m2
5/8" Regular Gypsum Board	12577.389	m2
6 mil Polyethylene	7629.577	m2
Aluminum	9.7544	Tonnes
Batt. Fiberglass	4318.3387	m2 (25mm)
Commercial(26 ga.) Steel Cladding	2081.821	m2
Concrete 20 MPa (flyash av)	1449.9416	m3
Concrete 30 MPa (flyash av)	456.4569	m3
Concrete Blocks	14789.924	Blocks
EPDM membrane	642.7415	kg
Expanded Polystyrene	4557.162	m2 (25mm)
Galvanized Decking	64.7207	Tonnes
Galvanized Sheet	13.5023	Tonnes
Galvanized Studs	33.3427	Tonnes
Hollow Structural Steel	17.408	Tonnes
Joint Compound	12.7425	Tonnes
Low E Tin Glazing	565.3382	m2
Modified Bitumen membrane	1862.0619	kg
Mortar	47.094	m3
Nails	1.2038	Tonnes
Open Web Joists	50.0832	Tonnes
Paper Tape	0.1462	Tonnes
Rebar, Rod, Light Sections	121.8349	Tonnes
Screws Nuts & Bolts	21.2679	Tonnes
Small Dimension Softwood Lumber, kiln-dried	1.5811	m3
Solvent Based Alkyd Paint	145.724	L
Standard Glazing	35.2809	m2
Water Based Latex Paint	1682.7441	L
Welded Wire Mesh / Ladder Wire	2.6413	Tonnes
Wide Flange Sections	369.8732	Tonnes

The values generated by Athena Impact Estimator in the bill of materials are approximate estimations of the material quantities used to construct the building. The assumptions made during the process of completing the LCA study of EOS Main building contribute to the amount of uncertainty in the values. The five largest amounts of materials were chosen for analysis by both looking at the BoM table and by considering the building structure and envelope.

The concrete block quantity was noticeably the largest value in the BoM table. It is one of the main structural materials used in EOS Main. Concrete blocks were used extensively in the basement, both as exterior and interior walls. The estimated quantity as shown in the table is 14,790 blocks. Assumptions were made regarding the thickness of the blocks used in the basement; the 10” thick blocks (2.1.1) were modelled in IE as 8” thick blocks and this makes the approximate quantity in the BoM an underestimate of the real quantity used in the building.

Wide flange steel sections are also of large quantity; as shown in the table, the building has a total of 369.9 Tonnes used in its structure. As mentioned in the Building Model section of the report, the first, second, and third floors of the building are all composed of steel beams and columns which have contributed to this large value in the BoM table. The assumptions made in the modelling of the building in IE should have no major effects on the quantity of wide flange steel sections produced in the BoM.

Another large quantity in the BoM was the quantity of gypsum wallboard; a total estimated value of 12577.389 m^2. The architectural drawing 402-06-005 indicates that all walls in EOS Main have drywall finish but due to IE’s limited choices of wall finish, regular gypsum wallboard was selected as noted in the Annex A and Annex B. The generated BoM overestimates the amount of gypsum wallboard used in the building due to the fact that gypsum was used as a surrogate material instead of drywall. The large value of the gypsum wallboard in the generated BoM table shows the significance of wall finish in EOS Main.

As was expected, concrete (20 MPa) is also one of the five largest values in the BoM table, with a value of 1449.9 m^3. The amount of concrete used in the structure of the building is significantly large. Concrete has been used as slab on grade, toppings on OWSJ of floors and roof, and also as walls. No major assumptions were made when inputting concrete values, therefore, the estimated BoM quantity is neither an over nor an underestimate.

Commercial steel cladding was another significant quantity in the table. The building's exterior cladding is of aluminum panels but since the Impact Estimator does not offer such material in the wall claddings, the building was assumed to have steel cladding. As noted in Annex A, commercial steel cladding is used in steel stud exterior walls (2.3.1 and 2.3.2) as part of their assembly. The BoM of EOS Main showed that this assembly contributed significantly to the materials required construction of the building.

SUMMARY MEASURES

The Athena Impact Estimator generated summary measures tables by Life Cycle Stages for the building. For the purposes of this LCA study on EOS Main the service life of the building model was set to one year in order to avoid uncertainties rising from maintenance of the building. Therefore the life cycle stages were limited to construction, manufacturing, and end-of-life. The measures available in the Impact Estimator include primary energy consumption, weighted resource use, global warming potential, acidification potential, human health respiratory effects, eutrophication potential, and smog potential.

The primary energy quantity includes all direct and indirect energy used to manufacture and transfer the building material. The manufacturing process takes into account the energy required to transport and use the raw material to construct the building. In addition, the Impact Estimator takes into considerations the indirect energy use associated with processing, transporting, converting and delivering fuel and energy (Athena Impact Estimator).

The weighted resource use values reported by the Impact Estimator are the sum of the weighted resource requirements for all products used in each of the designs. They can be thought of as "ecologically weighted kilograms", where the weights reflect expert opinion about the relative ecological carrying capacity effects of extracting resources. Excluded from this measure are energy feedstocks used as raw materials (Athena Impact Estimator). Weighted resource use is the same as normal resource converted to mass quantities except:

$$\text{Resource Use} = M_{\text{Fossil Fuels}}*1.0 + M_{\text{Limestone}}*1.5 + M_{\text{Iron Ore}}*2.25 + M_{\text{Coal}}*2.25 + M_{\text{Wood Fiber}}*2.5$$

Global warming potential is a reference measure based on equivalent CO_2. Carbon dioxide is the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO_2 equivalence effect" which is simply a multiple of the greenhouse potential of carbon dioxide.

Acidification is a more regional rather than global impact effecting human health when high concentrations of nitrogen oxides (NO_x) and sulfur dioxide (SO_2) are attained. The acidification potential of an air or water emission is calculated on the basis of its H^+ equivalence effect on a mass basis.

Human health respiratory effects consider the impact of particulate matter on human health. Some impacts of particulate matter on humans include sicknesses such as asthma, bronchitis and acute pulmonary disease.

Eutrophication is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to water it leads to the proliferation of aquatic photosynthetic plant life. This may lead to a chain of further consequences ranging from foul odors to the death of fish. The calculations in IE are expressed on an equivalent mass of nitrogen (N) basis. (Athena IE)

Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). This indicator is expressed in IE on a mass of equivalent NOx basis (Athena IE). The summary measures table by life cycle stages generated by IE for the EOS Main building is shown below:

TABLE 3 - SUMMARY MEASURES BY LCS

	Manufacturing	Construction	End-of_life	Total Effects
Measures	Total (material +transpo)	Total (material +transpo)	Total (material +transpo)	
Primary Energy MJ	24620435.77	1683011.35	176688.86	26480135.98
Weighted Resource Use kg	7365831.84	6962.98	169.44	7372964.26
GWP(kg CO2 eq)	1635751.85	22017.08	476.36	1658245.30
Acidification (moles of H+ eq)	526183.48	11121.44	113.88	537418.80
HHR Effects (kg PM2.5 eq)	4015.69	11.79	0.13	4027.61
Eutrophication (kg N eq)	863.38	10.05	0.11	873.54
Ozone (kg CFC-11 eq)	0.00	0.00	0.00	0.00
Smog (kg NOx eq)	4758.69	249.93	2.47	5011.09

SOURCES OF UNCERTAINTY

One of the largest sources of uncertainty in the LCA study of the EOS Main building is the uncertainty in time and space. For the purpose of this study, it was assumed that the building was being designed and constructed today; however, the building materials, technology and methods of construction may have changed since 1970.

The temporal uncertainty is caused by the life span of emission; different emissions last different amounts of time which is not considered in this study. The spatial uncertainty within this analysis stems from the fact that not all emissions occurred in the same place. Emissions can have different affects on the environment based on their location. The emissions released into the air generally have a greater travel potential than those released into the ground. Temperature and climate also play an important role in the amount of impact emissions can have on the environment; emissions could cause more damage in high temperatures rather than colder conditions.

Another source of uncertainty is the subjective choices made during process of completing the LCA. The Impact estimator includes mostly modern construction materials and many assumptions had to be made, surrogate materials had to be used, and values had to be modified to match the inputs of Athena IE. Although these have been noted in the IE_Inputs_Assumptions_Document they do affect the outcomes (BoM and Summary Measures Table) generated by Athena.

SENSITIVITY ANALYSIS

Sensitivity analysis was done on five material quantities to understand the effects different materials have on the overall environmental impacts. Sensitivity analysis is of high significance in the design phase of a building when decisions are being made on material quantities. For the sensitivity analysis of EOS Main, the following materials were chosen: commercial steel cladding, concrete block, concrete 20MPa, low E Tin glazing windows, and wide flange sections.

COMMERCIAL STEEL CLADDING

Sensitivity analysis was conducted on commercial steel cladding with a 10% increases in the quantity of the material. The 10% increase corresponded with a quantity increase of 182.96m^2. The largest impact was on Ozone depletion potential with a 3.4% difference. The second largest impact was on acidification potential with a .6% difference. The commercial steel cladding increase had little effect on other impact categories. The increases on the level of impact are due to the emission released during the manufacturing of the material. Based on the sensitivity analysis and the change in summary measures due to the addition of commercial steel cladding it is recommended to keep the quantity at low values in order to avoid ozone depletion potential.

TABLE 4 - COMMERCIAL STEEL CLADDING SENSITIVITY ANAYLSIS

Impact Category	% Difference
Primary Energy Consumption	0.44%
Weighted Resource Use	0.13%
Global Warming Potential	0.43%
Acidification Potential	0.57%
HH Respiratory Effects Potential	0.40%
Eutrophication Potential	0.39%
Ozone Depletion Potential	3.35%
Smog Potential	0.37%

CONCRETE 20MPA

A sensitivity analysis of 10% increase on concrete (20 MPa) showed a significant change in almost all of the impact categories. The most noticeable percentage change was in the weighted resource use with an increase of almost 5%. The second significant value was of Ozone depletion potential with a difference of 3.9%. The values of percentage change from the sensitivity analysis indicate that the overall impact of the building is very sensitive to quantity changes in concrete (20MPa). Decision makers need to consider the affects an increase in the quantity of concrete material could have on the environment; it is recommended to keep the quantity of concrete (20MPa) to a lower ratio compared to overall material quantities.

TABLE 5 - CONCRETE 20MPA SENSITIVITY ANALYSIS

Impact Category	% Difference
Primary Energy Consumption	0.75%
Weighted Resource Use	4.91%
Global Warming Potential	1.70%
Acidification Potential	2.08%
HH Respiratory Effects Potential	2.06%
Eutrophication Potential	0.77%
Ozone Depletion Potential	3.85%
Smog Potential	2.97%

CONCRETE BLOCK

Concrete blocks were used in both external and internal wall assemblies in the basement of EOS Main. A sensitivity analysis on the concrete blocks, with a 10% increase, showed no significant increase in the percentage difference of impact categories; the highest impact was on Ozone depletion potential with a change of 0.3%. The results showed that a change in the quantity of concrete blocks does not have a devastating impact on the environment and it is preferred to other similar materials (see sensitivity analysis for concrete 20 MPa).

TABLE 6 - CONCRETE BLOCK SENSITIVITY ANALYSIS

Impact Category	% Difference
Primary Energy Consumption	0.11%
Weighted Resource Use	0.02%
Global Warming Potential	0.19%
Acidification Potential	0.25%
HH Respiratory Effects Potential	0.23%
Eutrophication Potential	0.07%
Ozone Depletion Potential	0.33%
Smog Potential	0.26%

LOW EMISSIVITY TIN GLAZED WINDOWS

Low emissivity tin glazed windows were used extensively on first, second, and third floor exterior walls. A sensitivity analysis on the windows showed a 0.6% change on the human health respiratory effects potential. This is caused by the particulate matter which is released during the manufacturing of the glass. It is important to note the impact of increasing material quantity on the human health respiratory effects potential, however, the change on the impact itself is not that significant and compared to other materials it is relatively low.

TABLE 7 - LOW E TIN GLAZED WINDOWS SENSITIVITY ANALYSIS

Impact Category	% Difference
Primary Energy Consumption	0.02%
Weighted Resource Use	0.03%
Global Warming Potential	0.09%
Acidification Potential	0.15%
HH Respiratory Effects Potential	0.55%
Eutrophication Potential	0.06%
Ozone Depletion Potential	0.04%
Smog Potential	0.18%

WIDE FLANGE SECTIONS

The sensitivity analysis for a 10% increase in wide flange steel sections showed a percentage difference of 4.2% on primary energy consumption and a 4% difference on eutrophication potential. Other impact categories were also affected by a few percentages. The lowest percentage difference was on Ozone depletion potential. The designers and decision makers must be aware of the environmental impacts of each material used in construction of a building. It is advised to keep the quantity of wide flange steel section to a minimum wherever possible.

TABLE 8 - WIDE FLANGE SECTIONS SENSITIVITY ANALYSIS

Impact Category	% Difference
Primary Energy Consumption	4.15%
Weighted Resource Use	1.51%
Global Warming Potential	3.29%
Acidification Potential	2.36%
HH Respiratory Effects Potential	2.01%
Eutrophication Potential	4.05%
Ozone Depletion Potential	0.02%
Smog Potential	1.06%

As discussed above, sensitivity analysis in an LCA study shows how different quantities affect the overall impact of the building as a whole. With sensitivity analysis decision makers would have better understanding of the implications of material choices on environmental impacts. It would help them in choosing materials that would have the least effect on the impact categories shown above.

BUILDING PERFORMANCE

For the purposes of this study, the EOS Main building was modeled in the Athena Impact Estimator as it was designed and built in 1970. The original inputs were then modified and upgraded to meet the Residential Environmental Assessment Program's (REAP) insulation requirements. The upgrade was done by choosing a higher R-Value (thermal resistance of insulating materials) and changing the existing insulation materials to meet the requirements.

The building was upgraded to REAP’s standards in order to compare the current energy consumption to one with better insulation.

The EOS Main building’s walls were insulated with 2” thick batt insulation and the roof was insulated with 2” thick expanded polystyrene (shown on drawing 402-06-014). Fiberglass batt insulation has an R-value of 3.14 per inch; and the expanded polystyrene has an R-value of 4 per inch. The basement wall, which is composed of concrete blocks, provides additional insulations with an R-value of 1.11 per thickness. Therefore calculations had to be done to come up with a single R-value for the entire building’s wall assembly. The resulting R-value for the wall assembly is 7.03. The roof has a total R-value of 8.

R-values of windows was also calculated with respect to the type of windows, number of panes, and air space. Low emissivity double pane glasses have an R-value of 3.13; single standard glazing windows have an R-value of 0.91. The R-value of windows was calculated by weighting the R-values with respect to window areas and the calculations lead to a value of 3.10.

To upgrade the building to REAP’s standards the insulation within the walls and the roof were selected such that the R-values would be 20 and 40 respectively. The insulation in the improved building walls are still fiberglass batt, however, instead of having a thickness of 2”, they are now 6” thick. The roof insulation in the improved building is selected as 10” thick expanded polystyrene, and the windows were modeled as Silver Argon filled glazed windows in the improved building which resulted in an R-value of 3.95 (air movement added). The table below shows both the current and the improved R-values of EOS Main.

TABLE 9 - CURRENT VS. IMPROVED R-VALUES

		R-Value (ft2.degF.h/BTU)	
Assembly Type	Total Area (ft2)	'Current' Building	'Improved' Building
Exterior Wall	29011.17	7.03	20
Window	6401	3.00	3.97
Roof	23445	8.00	40
Weighted Average	58857.16667	6.98	26.20

The energy usage of the current building and the improved building were calculated based on the above R-values. The heat loss equation was used to calculate the energy usages:

Heat loss: $Q = A (\Delta T)/R$

Where, Q: heat loss,
A: external surface area,
ΔT: differential temperature (difference between inside and outside temperatures), and
R: the weighted average thermal resistance.

Having information about the current and the improved building's heat loss, one can find the energy pay-back period; the period it takes the improved building to verify it is more beneficial in terms of energy savings. The cumulative heat loss of the building was calculated by adding the annual operating energies every year to the original manufacturing and construction primary energy usages. The current heat loss and the improved heat loss were then plotted on a graph; the intersection of the two lines indicated the pay-back period to be approximately 1.5 years (Figure 1.0).

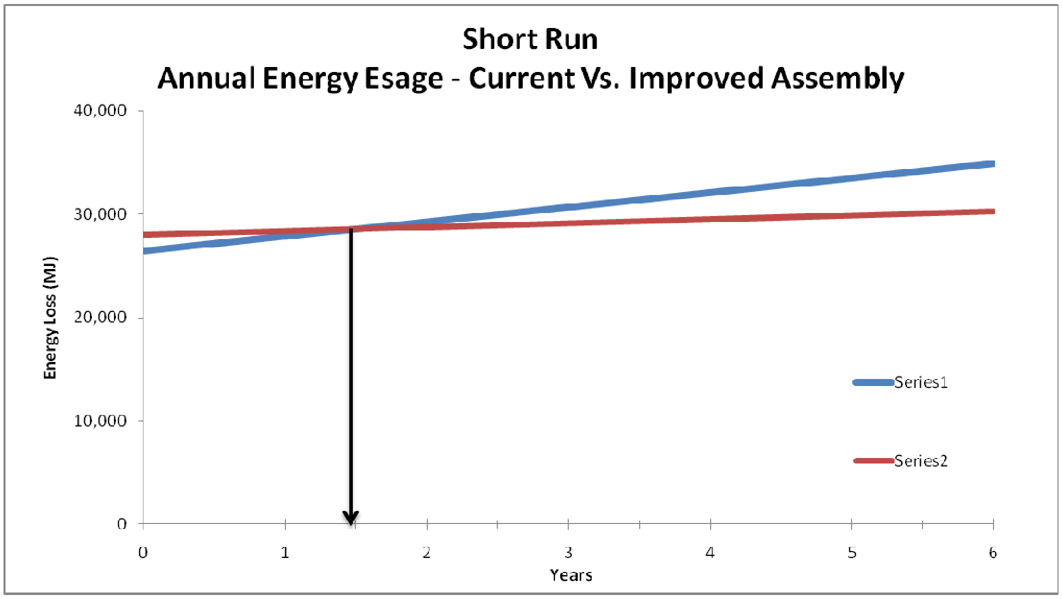

FIGURE 1 - SHORT RUN ENERGY COMPARISON

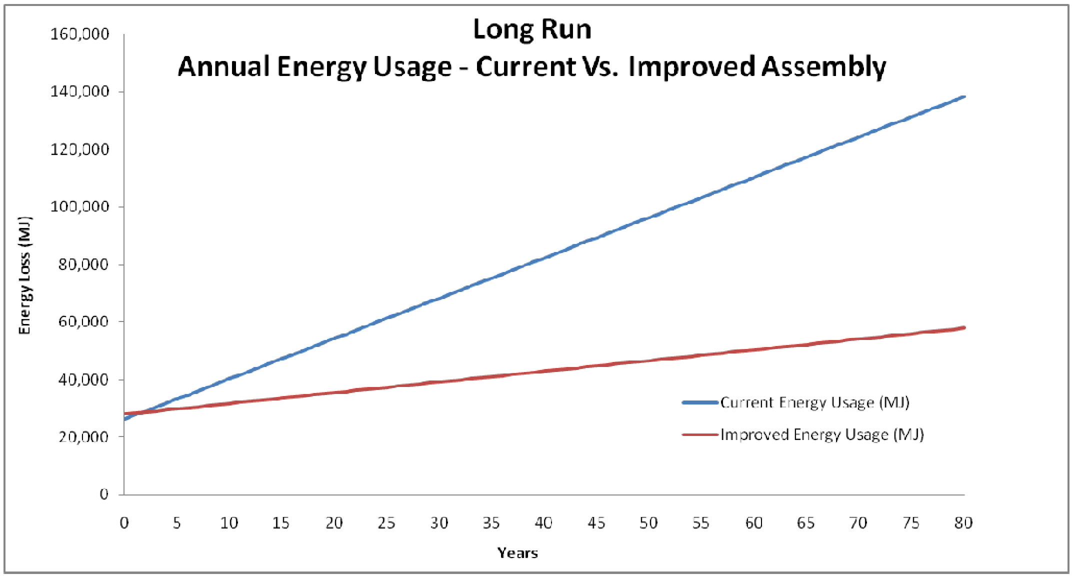

FIGURE 2 - LONG RUN ENERGY COMPARISON

The long run plot shows how much the improved building can save in terms of annual heat loss in 80 years. The difference of heat loss is calculated to be 58% which is of high significance. This shows that the improved building is worth investing in because even though the initial energy of construction and manufacturing of the improved building are higher, in the long run the savings associated with it are huge.

Given the above information regarding building performance, the current building could undergo renovation and building assemblies could be modified to increase thermal resistivity. If decided on renovating the building, it is recommended to keep the same insulation materials intact and add to their thickness; the same method was used when conducting the building performance analysis and as discussed the upgrades were worthy of the extra initial energy use. Renovations are costly and energy consuming, however, old buildings have poor envelope performance and even the slightest change to the building envelope can create big differences in the long run.

CONCLUSION

By conducting a cradle-to-gate LCA study on the EOS Main building, the impacts of the structure on the environment were quantified using Athena Impact Estimator's summary measures. The sensitivity analysis on major materials used in the construction of the building showed how a 10% quantity change can affect the building's overall impact on the environment. The materials with highest impacts were steel (wide flange) with a 4% change on primary energy use, and concrete (20 MPa) with 3.9% change on Ozone depletion potential. The two main environmental impacts of the building were the primary energy consumption and weighted resource use. The primary energy consumption of the building, during construction and manufacturing, was estimated to be 270 MJ/Sq ft. and the weighted resource use was 75.7 Kg/Sq ft.

Analysis of the EOS Main building performance shows that modifications should be looked into. These modifications could be done without having a complete demolition of the building; a simple addition to insulation materials of wall assemblies or a replacement of the old windows would suffice. If the modifications in EOS Main meet REAP's standards, then the difference in energy and heat loss savings can be as high as 50% in the long run.

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ANNEX A – IE INPUTS DOCUMENT

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 SOG_5"			
		Envelope	Length (ft)	146.77	177.37
			Width (ft)	146.77	177.37
			Thickness (in)	5	4
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Category	Vapour Barrier	
			Material	4 mil Poly	6 mil Poly
			Thichness (in)	-	-
	1.2 Concrete Footing				
		1.2.1 Footing_TypeA			
			Length (ft)	18	18
			Width (ft)	4.5	4.57
			Thickness (in)	20	19.7
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#6	#6
		1.2.2 Footing_TypeB			
			Length (ft)	11	11
			Width (ft)	5.5	6.70
			Thickness (in)	24	19.7
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#6	#6
		1.2.3 Footing_TypeC			
			Length (ft)	66	66
			Width (ft)	6	7.92
			Thickness (in)	26	19.7
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Rebar	#7	#6
		1.2.4 Footing_TypeD			

	Length (ft)	20.835	20.835
	Width (ft)	4.167	5.08
	Thickness (in)	24	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#6	#6
1.2.5 Footing_TypeE			
	Length (ft)	4	4
	Width (ft)	4	4.00
	Thickness (in)	18	18
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.6 Footing_TypeF			
	Length (ft)	80.01	80.01
	Width (ft)	2.667	2.667
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.7 Footing_TypeG			
	Length (ft)	8	8
	Width (ft)	3	3.00
	Thickness (in)	12	12
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#6	#6
1.2.8 Footing_TypeH			
	Length (ft)	50	50
	Width (ft)	5	5.58
	Thickness (in)	22	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#6	#6
1.2.9 Footing_TypeJ			
	Length (ft)	3.67	3.67
	Width (ft)	3.67	3.67
	Thickness (in)	18	18
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5

1.2.10 DeepFooting_1'x1'_Concrete			
	Length (ft)	22.38	22.38
	Width (ft)	22.38	13.63
	Thickness (in)	12.00	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.11 DeepFooting_2'6"x1'_Concrete			
	Length (ft)	39.12	39.12
	Width (ft)	39.12	23.83
	Thickness (in)	12.00	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.12 DeepFooting_2'x1'_Concrete			
	Length (ft)	65.91	65.91
	Width (ft)	65.91	40.15
	Thickness (in)	12.00	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.13 DeepFooting_3'x1'_Concrete			
	Length (ft)	20.78	20.78
	Width (ft)	20.78	12.66
	Thickness (in)	12.00	19.7
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
	Rebar	#5	#5
1.2.14 Stairs_Concrete_No1/West_64'/11"			
	Length (ft)	64.00	64.00
	Width (ft)	4.167	4.167
	Thickness (in)	11	11
	Concrete (psi)	4000	4000
	Concrete flyash %	-	average
	Rebar	#4	#4
1.2.15 Stairs_Concrete_No2/NorthSide_64'/11"			
	Length (ft)	64.00	64.00
	Width (ft)	4.167	4.167
	Thickness (in)	11	11
	Concrete (psi)	4000	4000
	Concrete flyash %	-	average

			Rebar	#4	#4
		1.2.16 Stairs_Concrete_No3/Core_100'/11"			
			Length (ft)	100.00	100.00
			Width (ft)	4.167	4.167
			Thickness (in)	11	11
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#4	#4
		1.2.17 Stairs_Concrete_No4/East_23.3'/11"			
			Length (ft)	23.30	23.30
			Width (ft)	4.167	4.167
			Thickness (in)	11	11
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#4	#4
2 Walls					
	2.1 Concrete Block Wall				
		2.1.1 Wall_External_ConcreteBlock_Basement_10"			
			Length (ft)	667	667
			Height (ft)	3.667	3.667
			Door Type	Steel	Steel exterior door
			Number of Doors	3	3
			Number of Windows	35	35
			Type of Windows	standard glazing	standard glazing
			Total Window Area (ft2)	376	376
			Rebar	#5	#5
		Envelope	Category	Insulation	Insulation
			Material	batt Insulation	Fiberglass Batt
			Thickness	2"	2"
			Category	Vapour Barrier	Vapour Barrier
			Material	Poly (6mil)	Poly (6mil)
			Category	Gypsum board	Gypsum Board
			Material	drywall	Gypsum Regular 5/8"
			Category	paint	paint
			Material	Latex Waterbased	Latex water based
		2.1.2 Wall_Internal_ConcreteBlock_Basement_8"			
			Length (ft)	779	779
			Height (ft)	13.67	13.67

	Door Opening	Rebar	#4	#4
		Number of Doors	15	15
		Door Type	Internal doors	hollow core wood interior
2.2 Cast In Place				
	2.2.1 Wall_CastInPlace_Core_AllFloors			
		Length (ft)	616	616
		Height (ft)	13.70	13.70
		Thickness (in)	12	12
		Concrete (psi)	4000	4000
		Concrete flyash %	-	average
		Rebar	#4	#5
		Number of Doors	4	4
		Door Type	wood dorrs with glass	Hollow core wood internal
		Thickness	-	-
2.3 Steel Stud				
	2.3.1 Wall_External_SteelStud_First and Second Floors_1'7"			
	Envelope	Length (ft)	1318	1318
		Height (ft)	13.5	13.5
		Number of Doors	7	7
		Door Type	Steel frame doors with glass	Steel exterior door
		Number of Windows	165	165
		Type of windows	Low E tin	Low E tin glazing
		Total Window Area (ft2)	4152	4152
		Sheathing Type	-	-
		Stud Spacing	20'	24oc
		Stud Weight	-	Heavy (20Ga)
		Stud Thickness	8x8	1 5/8 x 8
		Category	Paint	
		Material	Latex Paint	Latex water based
		Thickness	-	-
		Category	drywall	Gypsum Board
		Material		Gypsum Regular 5/8"
		Thickness	-	-
		Category	Insulation	Insulation
		Material	Rigid Insulation	Fiberglass Batt
		Thickness (in)	2	2
		Category	Vapour Barrier	Vapour Barrier
		Material	Poly (6mil)	6 mil

					Polyethylene
			Thickness (in)	-	-
			Category	Cladding	Cladding
			Material	Aluminunm panles	Steel Cladding - Commercial (26 ga.)
			Thickness (in)	-	-
		2.3.2 Wall_External_SteelStud_ThirdFloor_1'7"			
		Envelope	Length (ft)	660	660
			Height (ft)	13.29	13.29
			Number of Doors	2	2
			Door Type	Steel frame doors with glass	steel exterior
			Number of Windows	76	76
			Type of windows	Low E tin	Low E tin glazing
			Total Window Area (ft2)	1873	1873
			Sheathing Type	-	-
			Stud Spacing	20'	24oc
			Stud Weight	-	Heavy (20Ga)
			Stud Thickness	8x8	1 5/8 x 8
			Category	Paint	
			Material	Latex Paint	Latex water based
			Thickness	-	-
			Category	drywall	Gypsum Board
			Material		Gypsum Regular 5/8"
			Thickness	-	-
			Category	Insulation	Insulation
			Material	batt Insulation	Fiberglass Batt
			Thickness (in)	2	2
			Category	Vapour Barrier	Vapour Barrier
			Material	Poly (6mil)	6 mil Polyethylene
			Thickness (in)	-	-
			Category	Cladding	Cladding
			Material	Aluminunm panles	Steel Cladding - Commercial (26 ga.)
			Thickness (in)	-	-
		2.3.3 Wall_Internal_SteelStud_Type2			
			Length (ft)	3773	3773
			Height (ft)	13.7	13.7
			Sheathing Type	None	None

			Stud Spacing	-	16oc
			Stud Weight	-	Light (25Ga)
			Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Door Opening	Number of Doors	103	103
			Door Type	internal doors	Hollow core wood internal
		Envelope	Category	-	gypsum board
			Material	drywall	Gypsum Regular 5/8"
			Thickness	2"	-
			Category	paint	paint
			Material	Latex Water based	Latex water based
		2.3.4 Wall_Internal_SteelStud_Type3			
			Length (ft)	68	68
			Height (ft)	13.7	13.7
			Sheathing Type	None	None
			Stud Spacing	16 oc	16oc
			Stud Weight	-	Light (25Ga)
			Stud Thickness	1 5/8 x 3 5/8	1 5/8 x 3 5/8
		Envelope	Category	-	gypsum board
			Material	fire-rated drywall	Fire-rated gypsum type X 1/2"
			Thickness	2"	-
			Category	paint	paint
			Material	Latex Water based	Latex water based
		2.3.5 Wall_Internal_SteelStud_Type4			
			Length (ft)	75	75
			Height (ft)	13.7	13.7
			Sheathing Type	None	None
			Stud Spacing	16 oc	16oc
			Stud Weight	-	Light (25Ga)
			Stud Thickness	1 5/8 x 6	1 5/8 x 6
		Envelope	Category	-	gypsum board
			Material	drywall	Gypsum Regular 5/8"
			Thickness	2"	-
			Category	paint	paint
			Material	Latex Water based	Latex water based
3 Columns and Beams					
	3.1 Concrete Column				
		3.1.1 Column_Concrete_Basement			
			Number of	0	0

			Beams		
			Number of Columns	62	62
			Floor to floor height (ft)	14.5	14.5
			Bay sizes (ft)	47.00	40.00
			Supported span (ft)	16.17	19.91
			Live load (psf)	100	100
	3.2 Steel Column				
		3.2.1 Column_Steel_FirstFloor_HSS			
			Number of Beams	33	33
			Number of Columns	30	30
			Floor to floor height (ft)	13.5	13.5
			Bay sizes (ft)	47.00	40.00
			Supported span (ft)	16.67	23.04
			Live load (psf)	100	100
		3.2.2 Column_Steel_SeocndFloor_HSS			
			Number of Beams	33	33
			Number of Columns	37	37
			Floor to floor height (ft)	13.5	13.5
			Bay sizes (ft)	47.00	40.00
			Supported span (ft)	19.17	35.94
			Live load (psf)	100	100
		3.2.3 Column_Steel_ThirdFloor_HSS			
			Number of Beams	33	33
			Number of Columns	37	37
			Floor to floor height (ft)	13.29	13.29
			Bay sizes (ft)	47.00	40.00
			Supported span (ft)	19.17	35.94
			Live load (psf)	100	100
4 Floors					
	4.1 Concrete Suspended Slab				
		4.1.1 Floor_ConcreteSuspendedSlab_FirstFloor			
			Floor Width (ft)	1,037.50	1,037.50
			Span (ft)	16.67	16.67
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average

			Live load (psf)	-	75
	4.2 OWSJ				
		4.2.1 Floors_OWSJ_SecondFloor			
			Floor Width (ft)	1,224.45	1,224.45
			Span (ft)	19.17	19.17
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Live load (psf)	-	75
		4.2.2 Floors_OWSJ_ThirdFloor			
			Floor Width (ft)	1,224.14	1,224.14
			Span (ft)	19.17	19.17
			Concrete (psi)	3000	3000
			Concrete flyash %	-	average
			Live load (psf)	-	75
5 Roof	5.2 OWSJ				
		5.2.1 Roof_OWSJ			
		Envelope	Roof Width (ft)	1,223.00	1,223.00
			Roof Span (ft)	19.17	19.17
			Decking Type	1/2' Steel deck	-
			Decking Thickness	1/2'	5/8
			Category	Insulation	Insulation
			Material	Rigid Insulation	Fiberglass Batt
			Thickness	2"	2"
			Category	Vapour Barrier	Vapour Barrier
			Material	6mil Poly	6mil Polyethylene
			Thickness	-	-
			Category	SteelRoof System	SteelRoof System
			Material	-	Commercial

ANNEX B – IE INPUTS ASSUMPTIONS DOCUMENT

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Foundation	The Impact Estimator, SOG inputs are limited to being either a 4” or 8” thickness. Since the actual SOG thicknesses for the EOS Main building were not exactly 4” or 8” thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. The Impact Estimator limits the thickness of footings to be between 7.5” and 19.7” thick. As there are a number of cases where footing thicknesses exceed 19”, their widths were increased accordingly to maintain the same volume of footing while accommodating this limitation. Lastly, the concrete stairs were modelled as footings (ie. Stairs_Concrete_TotalLength). All stairs had the same thickness and width, so the total length of stair was measured and were combined into a single input.		
	1.1 Concrete Slab-on-Grade		
		1.1.1 SOG_5"	The flyash used is assumed to be average. The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[(25167 x (5”/12))/(4”/12)] = 177.37 feet
	1.2 Concrete Footing		
		1.2.1 Footing_TypeA	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintained, thicknesses were set at 19.7” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19.7”/12) = [(4.5’*4) x (20”/12)] / (19.7”/12)

			= 4.57 feet
		1.2.2 Footing_TypeB	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19.7” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19.7”/12) = [(5.5’*2) x (24”/12)] / (19.7”/12) = 6.7 feet
		1.2.3 Footing_TypeC	The rebar used in building is #7 but in Athena there's only #4,5,6, therefore rebar #6 was chose. The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19.7” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19.7”/12) = [(6’*6) x (26”/12)] / (19.7”/12) = 7.92 feet
		1.2.4 Footing_TypeD	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19.7” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19.7”/12) = [(4.167’*5) x (26”/12)] / (19.7”/12) = 5.08 feet

		1.2.7 Footing_TypeH	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured length was maintain, thicknesses were set at 19.7” and the widths were increased using the following calculations; = [(Cited Width) x (Cited Thickness)] / (19.7”/12) = [(5’*10) x (22”/12)] / (19.7”/12) = 5.58 feet
		1.2.10 Deepfooting_1'x1'_Concrete	The area of this was measured and multiplied by the cited thickness to get the volume. Then the calculated volume was divided by the square root of the measured area and then divided again by 19.7" to get the width of the footing at 19.7". This was done using the following calculations; = [[(Measured Area) x (Cited Thickness)] / sqrt(Measured Area)] / (19”/12)] = [[(501 ft2) x (12"/12)] / (501')^(1/2)] / (19.7”/12) = 13.63 feet
		1.2.11 Deepfooting_2'6"x1'_Concrete	The area of this was measured and multiplied by the cited thickness to get the volume. Then the calculated volume was divided by the square root of the measured area and then divided again by 19.7" to get the width of the footing at 19". This was done using the following calculations; = [[(Measured Area) x (Cited Thickness)] / sqrt(Measured Area)] / (19”/12)] = [[(1530 ft2) x (12"/12)] / (1530')^(1/2)] / (19.7”/12) = 23.83 feet

		1.2.12 Deepfooting_2'x1'_Concrete	The area of this was measured and multiplied by the cited thickness to get the volume. Then the calculated volume was divided by the square root of the measured area and then divided again by 19.7" to get the width of the footing at 19.7". This was done using the following calculations; = [[(Measured Area) x (Cited Thickness)] / sqrt(Measured Area)] / (19”/12)] = [[(4344 ft2) x (12"/12)] / (4344')^(1/2)] / (19.7”/12) = 40.15 feet
		1.2.13 Deepfooting_3'x1'_Concrete	The area of this was measured and multiplied by the cited thickness to get the volume. Then the calculated volume was divided by the square root of the measured area and then divided again by 19.7" to get the width of the footing at 19.7". This was done using the following calculations; = [[(Measured Area) x (Cited Thickness)] / sqrt(Measured Area)] / (19”/12)] = [[(432 ft2) x (12"/12)] / (432')^(1/2)] / (19.7”/12) = 40.15 feet
		1.2.14 Stairs_Concrete_No1/West_64'/11"	The thickness of the stairs was calculated to be 11 inches based on the cross-section structural drawings and details. Lengths were calculated by multiplying the stairs length by 2*number of floors on which they extend
2 Walls	The length of the concrete cast-in-place walls needed adjusting to accommodate the wall thickness limitation in the Impact Estimator. It was assumed that external steel stud walls were heavy gauge (20Ga) and interior steel stud walls were heavy gauge (25Ga).		
	2.1 Concrete Block Wall		
		2.2.1 Wall_External_ConcreteBlock_Basement_10"	Athena's concrete blocks are standard 200mm x 200mm x 400 mm (8" x 8" x 15"), so the 10" concrete block wall is modeled as 8". No sanblast finish available in IE so no finish was selected for the walls. Doors were set to steel exterior doors.
		2.2.1 Wall_Internal_ConcreteBlock_Basement_8"	In Athena, doors were selected as hollow core wood interior. Drywall was not an option for wall finish in IE so gypsum wallboard was selected instead of drywall for all wall types.
	2.2 Cast In		

	Place		
		2.2.1 Wall_CastInPlace_Core_AllFloors	Doors were set to hollow core wood.
	2.3 Steel Stud		
		2.3.1 Wall_External_Steel Stud_First and Second Floors_1'7"	Because 1st and 2nd floors have the same assembly and same floor to floor height, the length of wall and all openings were added up to represent one assembly. Doors (entrance and exit) were steel framed with glass, however, Athena does not have such doors therefore, steel exterior doors were selected. Entrance and exit doors (2 side doors) were counted twice to compensate for the smaller "door size" in Athena
		2.3.2 Wall_External_Steel Stud_ThirdFloor_1'7"	Exterior walls are covered with aluminum panels on the outside, however, Athena does not have aluminum panels as wall cladding therefore commercial steel cladding was selected. Also, steel exterior doors were selected in Athena.
		2.4.3 Wall_Internal_SteelStud_Type2	Stud spacing was assumed to be 16 o.c. 2" thick drywall was used on both sides but Athena does not have that type of drywall as part of wall assembly, therefore regular gypsum 5/8" was selected. All walls have Latex water based paint.
		2.4.4 Wall_Internal_SteelStud_Type3	Stud spacing was assumed to be 16 o.c. Firerated drywall was used on both sides, Athena does not have that drywall as part of wall assembly, therefore Fire Rated Type X Gypsum 1/2" was selected. Paint is on both sides and latex water based is selected
		2.4.5 Wall_Internal_SteelStud_Type4	Stud spacing was assumed to be 16 o.c. 2" thick drywall was used on one side, Athena does not have that drywall as part of wall assembly, therefore regular gypsum 5/8" was selected. Paint is on one side and latex water based is selected
3 Columns and Beams	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. This being the case, in OnScreen, since no beams were present in the EOS Main building's basement and first floor, concrete columns were accounted for on each floor, while each floor's area was measured. The number of		

	beams supporting each floor were assigned an average bay and span size in order to cover the measured area, as seen assumption details below for each input. The hollow structural steel (HSS) columns in the EOS Main building were modelled in Athena as HSS columns with the given live load of 100 psf.		
	3.1 Concrete Column	Basement contains concrete columns of different shapes and sizes (some circular and some square). The most common type was chosen to model the building's basement.	
		3.1.1 Column_Concrete_Basement	Because of the limitation of bay size (up to 40ft.) in Athena, the area was recalculated based on bay size 40ft. The new span size is calculated as shown: = (Original span)/ (Origianal floor width) * (Measured Supported Floor Area) / (40 ft. * 2) = (16.67ft) / (181 ft) * (17,292 /80) = 19.9 ft
	3.2 Steel Column		
		3.2.1 Column_Steel_FirstFloor_HSS	Because of the limitation of bay size (up to 40ft.) in Athena, the area was recalculated based on bay size 40ft. The new span size is calculated as shown: = (Original span)/ (Origianal floor width) * (Measured Supported Floor Area) / (40 ft. * 2) = (19.17 ft) / (width/50*2) * (17,292 /80) = 23.04 ft The area used for first floor is less than second and third floor becuase not all of it is OSWJ, there is also a slab used in first floor (due to different elevations in footigns) which is calculated as part of the concrete SOG. Beam type is selected WF Gerber.

		3.2.2 Column_Steel_SecondFloor_HSS	Because of the limitation of bay size (up to 40ft.) in Athena, the area was recalculated based on bay size 40ft. The new span size is calculated as shown: = (Original span)/ (Origianal floor width) * (Measured Supported Floor Area) / (40 ft. * 2) = (19.17 ft) / (area/50*3) * (23,469/80) = 35.94 ft
		3.2.3 Column_Steel_ThirdFloor_HSS	Because of the limitation of bay size (up to 40ft.) in Athena, the area was recalculated based on bay size 40ft. The new span size is calculated as shown: = (Original span)/ (Origianal floor width) * (Measured Supported Floor Area) / (40 ft. * 2) = (19.17 ft) / (area/50*3) * (23,463 /80) = 35.94 ft
4 Floors	The Impact Estimator calculated the thickness of the material based on floor width, span, concrete strength, concrete flyash content and live load. The only assumptions that had to be made in this assembly group were setting the live load to 75psf. Second floor, third floor, and roof structures all have concrete slabs covering steel material which is included in Athena IE.		
	4.1 Concrete Suspended Slab		
		4.1.1 Floor_ConcreteSuspendedSlab_FirstFloor	To calculate the floor width, divide the floor area by span size of 19.17ft. = 17292 sq ft/ 19.17 ft = 1037.53 ft.
	4.2 OWSJ		
		4.2.1 Floors_OWSJ_SecondFloor	To calculate the floor width, divide the floor area by span size of 19.17ft. = 23469 sq ft/ 19.17 ft = 1224.45 ft.
		4.2.2 Floors_OWSJ_ThirdFloor	To calculate the floor width, divide the floor area by span size of 19.17ft. = 23463 sq ft/ 19.17 ft = 1224.14 ft.
5 Roof	The live load was assumed to be 75 psf and the concrete strength was set to 4,000psi instead of the specified 3,500psi.		