A Life Cycle Assessment of the Mathematics Building

Dallas Nemec

University of British Columbia

CIVL 498C

March 2010

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.

A Life Cycle Assessment of the Mathematics Building

Civil 498c - Whole Building Life Cycle Assessment
Dallas Nemec

Submitted March 29, 2010

Abstract

A Life Cycle Assessment for the Mathematics Building at the University of British Columbia (UBC) has been completed in conjunction with 29 other buildings at the UBC campus. The ultimate goal is to have a database of LCA's for all buildings at UBC enabling comparisons to be made between buildings with different structure types, functions and over time. Only the structure and envelope are included in the building model and environmental impacts are only considered for the manufacture and construction phases. The Mathematics building, built in 1925, is a 2 story wood frame building and is comprised of 18 classrooms, 21 offices and a 250 person capacity lecture hall. 2 software programs - The Athena Sustainable Material Institute's Environmental Impact Estimator and OnCentre's OnScreen Takeoff - are used to assist with the material takeoff for the building. The EIE is used to assess the environmental impacts of building materials. The Math Building was found to have approximately 20 to 40% of the impacts per square foot that the average UBC building produces in terms of energy consumption, resource use, eutrophication potential, acidification potential, smog potential, human health effects potential and global warming potential. The high proportion of wood caused the ozone depletion potential to be 150% the average UBC building. Sensitivity analysis determined that the model is most sensitive to concrete for most impact categories and to wood for ozone depletion potential. Using a simple energy model, it was determined that if insulation is added to the walls and roof of the as built structure, the energy payback period is less than 2 weeks and the operating energy demand is reduced by 2,500GJ/year.

Table of Contents

List of Figures

List of Tables

1 Introduction

This report presents the findings from a whole building life cycle assessment for the Mathematics building at the University of British Columbia (UBC). The International Organization of Standards (ISO) document 14040, "Environmental Management – Life Cycle Assessment – Principles and Framework," was used as a guide for the LCA procedure. Two software programs were used to assist with the takeoff and environmental impact assessment. OnCentre's OnScreen Takeoff was used to assist with quantity takeoffs for the relevant assemblies in the building. The Athena Sustainable Materials Institute's Environmental Impact Estimator was used to assist with the material takeoff and compute the environmental impacts for the model.

The Mathematics building at UBC is located at 1984 Mathematics Road on the UBC Vancouver campus. The original name of the building was the Arts building and the name was changed to Mathematics building in 1960. The Math building was built in 1924/25 as a semi permanent building along with 8 other buildings. The other semi permanent buildings built at this time include Arts One, the Auditorium, Geography building, Math Annex, Mining Metallurgy and Hydraulics building, Mechanical Engineering Lab, Mechanical Engineering Annex and an Old administration building. The expected lifespan of these buildings was 40 years (University of British Columbia, 1936) and the total cost for all 9 buildings was $500,000. The building originally housed the Departments of Classics, Economics, Sociology and Political Science, English, History, Math, Modern Languages and Philosophy (UBC Archives).

The Math building is a two story wood frame structure with a stucco finish on the exterior. As built, the building had 18 classrooms, 21 offices, 6 bathrooms, 2 locker rooms, 2 faculty lounges and a large lecture room with seating for 250 people. The total area of functional space for the building was measured as 28580 square feet. Figure 1 on the next page shows a picture of the front entrance to the Math Building.

This report will provide the goal and scope definition for this project, takeoff details, a bill of materials for the model, summary impact measures, a comparison of impacts to other UBC buildings, a sensitivity analysis, a discussion of uncertainties for the study, an energy model with suggested improvements for energy efficiency, and an author's note.

Figure 1 - Front Entrance of the Math Building

2 Goal and Scope of Study

In this section, the study is explained in terms of the goals, reasons for study, intended audience, tools and methods used, functional unit for study, and impact categories considered.

2.1 Goal of Study

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

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the Math building. An exemplary application of these references are in the assessment of potential future performance upgrades to the structure and envelope of the Math 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 Math 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.

2.2 Scope of Study

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

2.2.1 Tools, Methodology and Data

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

The study will first undertake the initial stage of a materials quantity takeoff, which involves performing linear, area and count measurements of the building's structure and envelope. To accomplish this, OnScreen TakeOff version 3.6.2.25 is used, which is a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. Using imported digital plans, the program simplifies the calculation and measurement of the takeoff process, while reducing the error associated with these two activities. The measurements generated are formatted into the inputs required for the IE building LCA software to complete the takeoff process. These formatted inputs as well as their associated assumptions can be viewed in 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 Math 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 Math building. As this study is a cradle-to-gate assessment, the expected service life of the Math 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 Math 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 Math 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 Math building are the original architectural drawings from when the building was initially constructed in 1925. 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 limitations will be discussed further as they emerge in the Building Model section of this report and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Appendix B.

3 Building Model

This section will explain the methodology that was used in creating the model of the Math Building as well as present the bill of materials for the completed model. To assist with the material takeoff, two software programs were used for this project: OnCenter's OnScreen Takeoff (OST) and the Athena Sustainable Materials Institute's Environmental Impact Estimator (EIE). The Takeoff section that follows will describe how each of the programs was used in the modeling process. In addition, high level assumptions and general methodology for each structural component in the model will be covered. A bill of materials is provided in section 3.2 showing a complete list of materials for the model of the Math Building. Along with the bill of materials is a discussion on the five most used materials in the construction of the building as well as some of the assumptions influencing the materials and quantities on the bill of materials.

3.1 Takeoffs

The Athena Sustainable Materials Institutes Environmental Impact Estimator (EIE) and OnCenter's Onscreen Takeoff (OST) were used to assist in the takeoff of the building materials for the Math building. Onscreen Takeoff is a user friendly software that allows the user to import the original building drawings for the project of interest and the takeoff is done directly off of the scaled drawings. The program improves accuracy of the takeoff in addition to decreasing modeling time. Using OnScreen Takeoff, the user has the option of doing area takeoffs, linear takeoffs and counts. OST was used to get the lengths, areas and volumes of all the relevant building assemblies. These assemblies included foundations, walls, windows, doors, floors and roofs and all other components included in the structure and envelope of the building. The EIE has large databases cataloguing the materials used in the common construction of today's most popular building types. For each modeled component, the modeler is required to input the dimensional measurements as well as some general specifications for material and construction type, and the EIE completes the takeoff by assigning a complete list of materials used in the construction of the assembly. In this section, a brief discussion will be presented highlighting some of the high level assumptions and general methodology for each of the main structural assemblies. Complete documentation of all EIE inputs and assumptions made in building the model can be found in the Inputs Document and the Assumptions Document in Appendix A and B, respectively.

3.1.1 Foundations

Foundations were divided into footings and slabs on grade. The nomenclature for the slabs on grade follows the form: SOG_Thickness_Description for the OST and EIE inputs. The nomenclature for the footings follows the form: Footing_Name_Width_Description. Drawings 518-01-001, 518-06-008 and 518-06-009 provided the plans and details for the foundations for the Math building. Strip footings for the exterior and interior foundation walls were measured in OST using a linear condition with the width and depth taken from details on drawing 510-07-001. Square footings were counted based on dimension and the depth was assumed to be 12" for all footings based on the details for the footings shown in drawing 518-06-008. Figure 2 on the next page shows the plan view of the foundation with the takeoffs for the strip and square footings. Slabs On grade were measured using an area condition. All concrete stairs in the building were treated as slabs on grade with the thickness taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. Due to limited details for the stairs in the building, all stairs were based on the detail for the front entrance stairs shown in drawing 518-06-008. The concrete floor on the ground floor and first floor bathrooms were modeled as slabs on grade, as were the concrete landings at each of the entrances for the building. Concrete properties are not specified in the drawing set. Concrete strength is assumed to be 4000PSI and all rebar is assumed to be #4. Although there was likely no flyash used in the concrete for the construction of the Math building, the EIE requires a flyash input and average flyash was assumed. See Appendix A and B for the EIE inputs and assumptions documents for complete documentation of all inputs and assumptions made for the foundations.

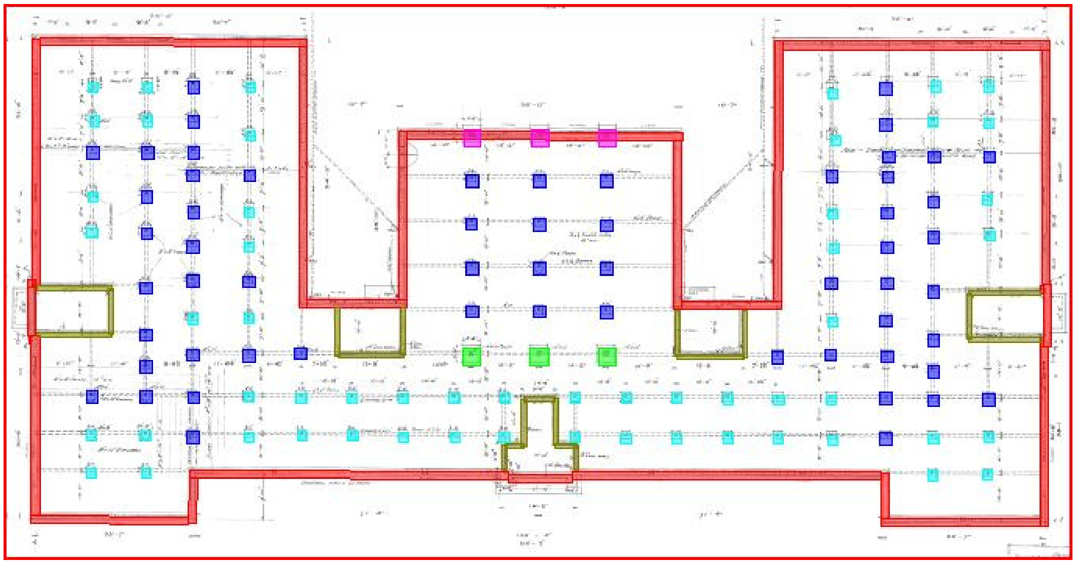


Figure 2 - Foundation Plan in OST with footing takeoffs shown

3.1.2 Walls

All walls were modeled in On Screen Takeoff using the linear condition. The two type of walls modeled for the Math building were wood stud walls and cast in place concrete walls. The nomenclature for the wood stud walls followed the form: Wall_WoodStud_Location_Description for both the OST and EIE inputs. The nomenclature for the cast in place walls followed the form: Wall_Cast-in-Place_Description. Windows and doors were named to match the walls the belonged to. Wood stud walls were assumed to be interior or exterior based on if they were in contact with the elements. The stud types were not specified in the drawings, and were assumed to be green wood. Stud spacing was not specified for majority of walls and was assumed to be 16 inches for all walls. Lath and Plaster was used to finish all interior walls. Due to EIE limitations, Lath and plaster was modeled as 1/2 inch of regular gypsum and laths which are accounted for with additional wood added as extra basic material in the EIE. While some of the doors had 20 percent glazing, all were modeled as solid wood due to EIE limitations. Due to EIE limitations, all doors were modeled as being 7'x32". Windows were measured in OST using area and area count takeoffs. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. While some windows are operable and some are not, all are modeled as operable. For exterior envelope system, drawings show that 3 coat stucco sits overtop chicken wire, vertical battens, paper, and shiplap. In the EIE, this envelope system was modeled as stucco over metal mesh and cedar shiplap siding. Shiplap is assumed to be cedar because all lath material used in building is cedar. Vertical battens are assumed to be negligible and paper cannot be modeled in EIE. Cast in place walls were used to model the concrete entranceway, as well as the foundation walls. No concrete properties were specified in the drawings. The concrete was assumed to be 4000psi, with average flyash and #5 rebar. See Appendix A and B for the EIE inputs and assumptions documents for complete documentation of all inputs and assumptions made for the walls.

3.1.3 Floors

Floors were measured in OST using area takeoffs. All floors in the building are wood joist and were modeled as such. The nomenclature for floors followed the form: Floor_WoodJoist_Location for the OST and EIE inputs. For each floor, an average span was found for a floor by finding a weighted average span. The EIE has a maximum span input of 14.96 feet. For Spans that were larger than this, 14.96 feet was used. Drawing 518-06-006 shows that shiplap is used as decking material, hence, cedar shiplap siding was added to the floors as decking material. Cedar is assumed because all the lath material for the building is shown as cedar. The Live Load was not given in the Drawings. In LCA report for the Geography building, by Jessica Connaghan, which was built in the same year and by the same architect, it states, "An assumed live load of 45psf was used based on drawing 401-07-001, a list of specifications from a 2004 renovation." Based on this, an assumed live load of 45PSF was used for all floors. See Appendix A and B for the EIE inputs and assumptions documents for complete documentation of all inputs and assumptions made for the floors. Below, Figure 3 shows a screenshot of the area takeoff for floors on the ground floor of the Math Building.

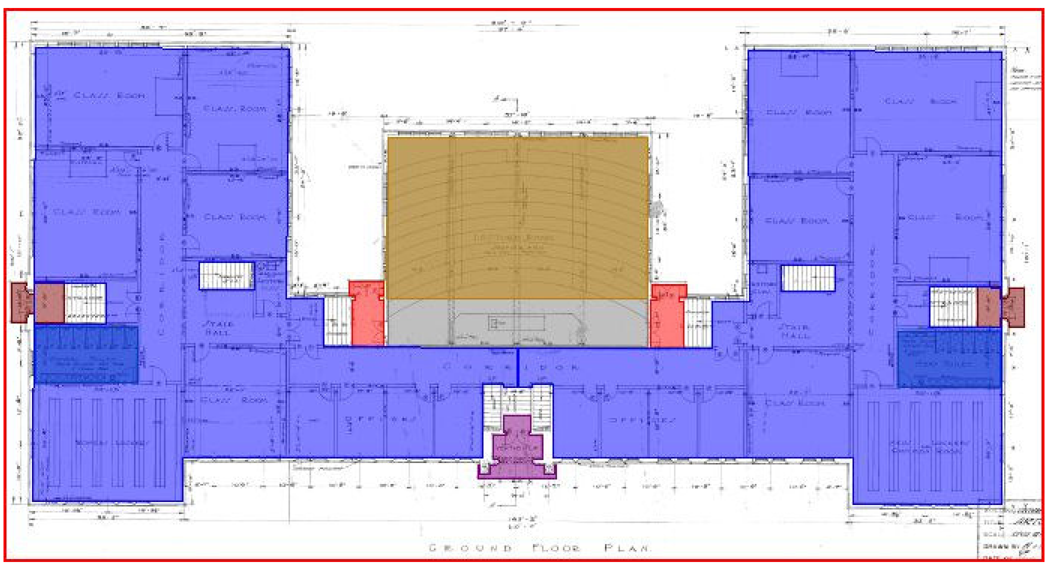


Figure 3 - OST screenshot showing area takeoffs for floors on the ground floor of the Math building

3.1.4 Roofs

Roofs were modeled similar to Floors. The building's roof was divided into a section over the lecture room and a section over the rest of the building. The roof was modeled as wood joist based on the drawing 518-06-008. The nomenclature for roofs followed the form: Roof_WoodJoist_Description_Location for the OST and EIE inputs. Like the floors, the max span input is 14.96 feet and this was used for the main building span although the true span was found to be 21.8 feet. Also, cedar shiplap siding was used to model the shiplap decking and a 45psf live load was assumed. For roofing material, drawing 518-06-006 shows that the roof system is “4 ply with gravel”. Roofing asphalt and aggregate stones were used to model the roof envelope. See Appendix A and B for the EIE inputs and assumptions documents for complete documentation of all inputs and assumptions made for the roofs.

3.1.5 Extra Basic Materials

All structures that did not fall into the categories listed previously were modeled as extra basic material (XBM). The nomenclature for extra building materials followed the form: XBM_Description for the OST and EIE inputs. The 3 trusses spanning the lecture room were modeled as large dimension softwood lumber for the timber sections and steel for the rods and plates. See Figure 4 for an image of the Truss detail. The foundation consists of a post and girder system to support the plinth (ground floor) and lecture room floor. The posts and girders were modeled as large dimension softwood lumber. It should be mentioned that the wood used for the posts, girders and truss were large 6x6 and larger timber sections. The input of softwood lumber would likely overestimate the environmental impact slightly due to the extra manufacturing processes. XBM’s is also where the laths from the lath and plaster were inputted into the EIE. Laths are typically 2 inches wide and ¼ inch thick and are spaced ¼ inch from each other (Wikipedia, 2008). Based on these dimensions, all lath and plaster wall sections were measured using the surface area measurement in OST for all relevant walls, and 8/9 of the wall area was considered to be covered in solid lath. The lath was then converted to a volume and inputted as small dimension softwood lumber. Although it is specified that the laths are cedar, they were not inputted as such due to limitations of the EIE for inputting thicknesses for cedar wood. The volume was able to be more accurately entered using the softwood lumber input. See Appendix A and B for the EIE inputs and assumptions documents for complete documentation of all inputs and assumptions made for the extra basic materials.

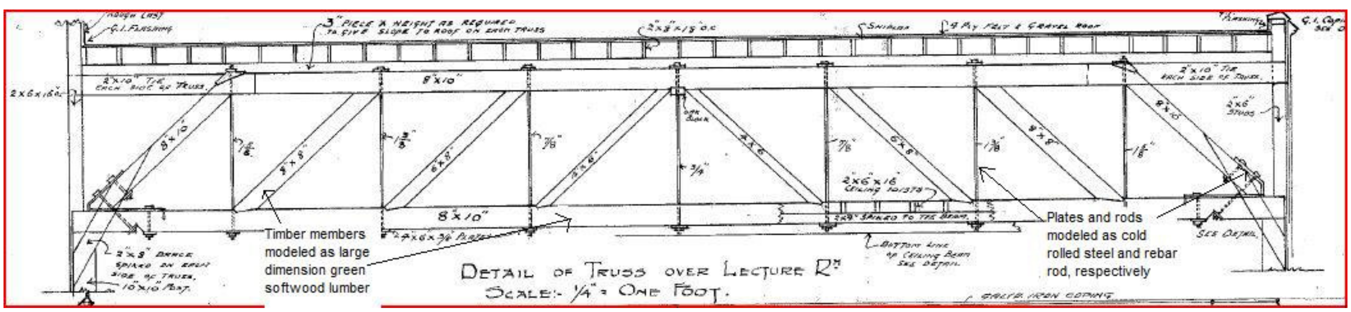


Figure 4 - Detail of the Trusses used to span the lecture room and notes on how material takeoff was performed

3.2 Bill of Materials

After the envelope and structure for the whole building was accounted for using OST and the EIE, a bill of materials was produced by the EIE showing a complete list of materials that went into the construction of the Math building model. It should be noted that this list of materials represents the modeled building, and materials may be under or over estimated, or may not exist in the real building at all. Table 1 below displays the bill of materials.

Table 1 - Bill of Materials for Math building EIE model

Material	Quantity	Unit
#15 Organic Felt	316.47	100sf
1/2" Regular Gypsum Board	67151.88	sf
Aluminum	2.30	Tons
Ballast (aggregate stone)	3363.58	lbs
Batt. Fiberglass	272.90	sf(1")
Cedar Wood Shiplap Siding	74062.38	sf
Cold Rolled Sheet	0.88	Tons
Concrete 30 MPa (flyash av)	248.28	yd^3
EPDM membrane	1041.74	lbs
Galvanized Sheet	2.66	Tons
Joint Compound	6.86	Tons
Large Dimension Softwood Lumber, Green	15.83	Mbfm
Large Dimension Softwood Lumber, kiln-dried	58.58	Mbfm
Nails	2.18	Tons
Paper Tape	0.08	Tons
Rebar, Rod, Light Sections	4.39	Tons
Roofing Asphalt	3203.41	lbs
Small Dimension Softwood Lumber, Green	72.55	Mbfm
Small Dimension Softwood Lumber, kiln-dried	14.21	Mbfm
Standard Glazing	3689.53	sf
Stucco over metal mesh	28273.85	sf
Water Based Latex Paint	308.37	US Gallon
Welded Wire Mesh / Ladder Wire	0.22	Tons

After a quick glance at the bill of materials, it becomes obvious that the Math building is primarily a wood structure. Furthermore, it can be seen that the building is mostly made up of a select number of products or materials. The five most used materials in the building appear to be regular gypsum board (and joint compound), cedar shiplap siding, concrete, softwood lumber and stucco over metal mesh. These five materials will now be discussed briefly in terms of the assemblies that required them, and any assumptions made that may have influenced the results.

Regular gypsum board and joint compound appear to be some of the most plentiful materials used in the construction of the Math building. Gypsum board (and joint compound) was used to model all lath and plaster walls in the building. Lath and plaster was used in the building for all interior exposed walls. In addition to the gypsum board, laths were included in the model by adding softwood lumber as extra basic material. It is possible that gypsum board has a higher environmental impact than just plain plaster due to the added manufacturing process to create gypsum board. Also, ½ inch of gypsum board may over or underestimate the actual material on the walls depending on the thickness of the plaster. Plaster is typically at least ½ inch, and usually not much more, so the volume takeoff should be close.

Cedar shiplap siding was used to model all shiplap in the building. Drawings show that shiplap existed on all exterior exposed walls and as sheathing for the floors and roof. Due to EIE limitations, all shiplap had to be entered as wall cladding material and the program automatically added latex paint to the shiplap. This caused a large volume of latex paint to be added to the model. From drawing 518-06-006 it can be seen that the shiplap was approximately 1 inch thick. It is not stated in the EIE what thickness was used for the shiplap material and any deviation from 1 inch for the EIE shiplap would over or underestimate the true value of shiplap in the building.

In the EIE, softwood lumber was further divided into small and large dimension softwood lumber as well as green or kiln dried for each type. Large dimension lumber is defined as 2x8's and larger, while small dimension lumber is classified as 2x6 lumber and smaller. All of the walls in the structure (excluding foundation) were wood stud and the floor and roof was wood joist. Other structures that were modeled as softwood lumber included wood stairs, truss material, foundation posts and girders and the laths on interior walls. Where possible, softwood lumber was inputted as being green rather than kiln dried since it is more likely that in 1925 softwood lumber would have been green. The program automatically inputs kiln dried wood for portions of the wall and floor structures which explains the presence of the kiln dried wood in the bill of materials. Large size timber members were used for the trusses as well as the posts and beams in the foundation and these were modeled as green large dimension softwood lumber. The environmental impact of dimension lumber would likely be higher than the timber members due to the added manufacturing process. Laths for the interior walls are known to be cedar but were inputted as green small dimension lumber. As was mentioned in the takeoff section, this was done to more accurately input the volume of lath material.

Concrete is used for the footings, foundation walls, some stairs, bathroom floors and some entranceways. There were no major assumptions made with regards to using concrete to model each of these assemblies. There was some estimation required to model the height of the interior and exterior walls due to a lack of detail in the drawings and this estimation may have led to a slight over or under estimation of concrete for these walls.

Stucco over metal mesh was used to model the stucco finish on all exterior walls. The actual building described the exterior finish as "stucco over chicken wire," and this is believed to be accurately captured with the stucco over metal mesh input into the EIE. Because the drawings were complete for the exterior wall are, the accuracy for this takeoff is expected to be very good.

Some materials that may appear questionable for this building are explained here. The aluminum in the structure is due to the hardware for the operable windows. The fiberglass batt insulation was automatically put into the model when adding windows and is not present in the actual building. EPDM membrane (waterproofing membrane) is automatically added to the model when windows are added and is not present in the actual building.

4 Summary Measures

In this section, the environmental impacts are discussed and the outputs from the EIE are presented and examined. These results will be looked at in terms of summary measures over the life cycle stages, as well as overall in comparison to other UBC buildings. In addition, section 4.4 provides a sensitivity analysis to examine the sensitivity of the model to the most used materials in the building. Understanding the uncertainties inherent in the Impact Assessment is important in reviewing any LCA and there is a discussion at the end of this section on the uncertainties for this study.

4.1 Impact Categories Considered

As was mentioned in the scope for the project, the impact categories considered were: Global warming potential, acidification potential, eutrophication potential, ozone depletion potential, photochemical smog potential, human health respiratory effects potential, weighted raw resource use and primary energy consumption. A brief description will now be made for each of the impact categories. The Athena Sustainable Material Institute's EIE help section provided the bulk of the information provided in this section.

Global warming potential is measured in CO_2 equivalents and refers to the chemical compounds that cause a heat trapping effect in the atmosphere. Global warming potential comes from energy combustion and raw material processing and occurs during material extraction, manufacturing, transportation and construction.

Acidification potential impacts are more region specific than global. The acidification potential impact is based on the air and water outputs containing H^+ ions on a mass basis. Acidification can be harmful to aquatic and land based life.

Eutrophication potential refers to the over nitrifying of surface waters, causing overgrowth of algae and potentially affecting aquatic life. The impact is calculated based on a Nitrogen equivalent output basis.

Ozone Depletion Potential is measure based on the CFC-11 equivalents released during the manufacture and use phase of materials. Ozone depletion is caused by a number of chemical compounds including CFC-11, halons and HFC's.

Photochemical Smog potential is based on the NO_x equivalents being emitted into the atmosphere. Smog potential is primarily a region specific impact. Smog forms when certain transportation and industry emissions are trapped at ground level and react with sunlight.

Human health respiratory effect potential is based on potentially dangerous particulate matter released into the atmosphere. Particulate matter of various sizes can have a detrimental effect on human health and is caused by emissions from fuel combustion and industrial activities.

Weighted resource use refers to the "ecologically weighted mass" of resource use. The EIE weights some materials as having a larger impact than others when it comes to resource use, such as wood fibers and coal. Most resources, however, including fossil fuels, are given a weight of 1. Weighted resource use is given in tons and takes into account the impact of materials on the worlds finite resources.

Primary Energy Consumption is given in mega joules and refers to the total embodied energy for materials. Embodied energy in materials results from the total direct and indirect use of energy coming from the activities of material extraction, processing, transportation and construction.

In many cases the impacts occur in combination with each other. For example, transportation of materials by truck impacts the energy consumption (fuel), weighted resource use (fuel), human health effects (particulate matter in emissions), Smog potential (NO_x in emissions) and global warming potential (CO_2 in emissions).

4.2 Summary Measures over the Construction and Manufacturing Stages

This study only considered the environmental impacts of the construction and manufacturing stages of the Math building. In this way, it is easier to maintain consistent study practices over other UBC buildings and comparisons can be made for the manufacturing and construction phase between different buildings. Table 2 below shows the summary measures for the manufacturing and construction impacts for the Math building.

Table 2 - Summary Measures for Construction and Manufacturing Impacts of Math Building

	Manufacturing			**Construction**			**Combined**	
	Material	Transportation	**Total**	Material	Transportation	**Total**	**Combined Total**	**Combined Per Sq. Ft.**
Primary Energy Consumption MJ	2041371.70	80018.74	**2121390.44**	40598.36	121464.74	**162063.10**	**2283453.53**	**79.90**
Weighted Resource Use kg	1257013.22	54.51	**1257067.72**	925.37	80.34	**1005.71**	**1258073.43**	**44.02**
Global Warming Potential (kg CO2 eq)	152426.28	146.49	**152572.77**	3926.96	225.82	**4152.78**	**156725.55**	**5.48**
Acidification Potential (moles of H+ eq)	71194.06	48.51	**71242.57**	2099.88	71.63	**2171.51**	**73414.08**	**2.57**
HH Respiratory Effects Potential (kg PM2.5 eq)	785.77	0.06	**785.83**	2.14	0.09	**2.23**	**788.05**	**0.03**
Eutrophication Potential (kg N eq)	59.30	0.05	**59.35**	1.57	0.07	**1.64**	**61.00**	**2.13E-03**
Ozone Depletion Potential (kg CFC-11 eq)	2.56E-03	6.02E-09	**2.56E-03**	1.31E-10	9.25E-09	**9.38E-09**	**2.56E-03**	**8.96E-08**
Smog Potential (kg NOx eq)	716.98	1.09	**718.07**	38.68	1.60	**40.28**	**758.35**	**0.03**

From table 2, it can be seen that the vast majority of the impacts occur at the manufacturing stage. Furthermore, of the manufacturing impacts, most of these are due to the materials. Construction impacts are much lower in magnitude compared to the manufacturing impacts and mostly arise due to transportation of the various the materials and equipment during construction.

4.3 Comparison of Impacts to other UBC buildings

By looking only at impacts in terms of absolute values, it can be hard to understand whether the building is doing a good or poor job in terms of environmental impact performance. In order to better gauge the performance of the building, it is helpful to compare it to other buildings in terms of impacts per square foot of functional space. In this way, the buildings are found to cause different net impacts to the environment to provide the same function, and comparisons can be made across different building types. Figure 5 shows the impacts of the Math building in comparison to the average of other UBC buildings. The UBC buildings that were considered were Geography, Hennings, Buchanon, MacMillan, CEME, FSC and AERL. It should be noted that the EIE has had different versions available for use and that the results for each building could be affected by the version that was used. Furthermore, as LCA results are completed for more UBC buildings, the UBC average will change to represent a larger sample of the UBC buildings on campus.

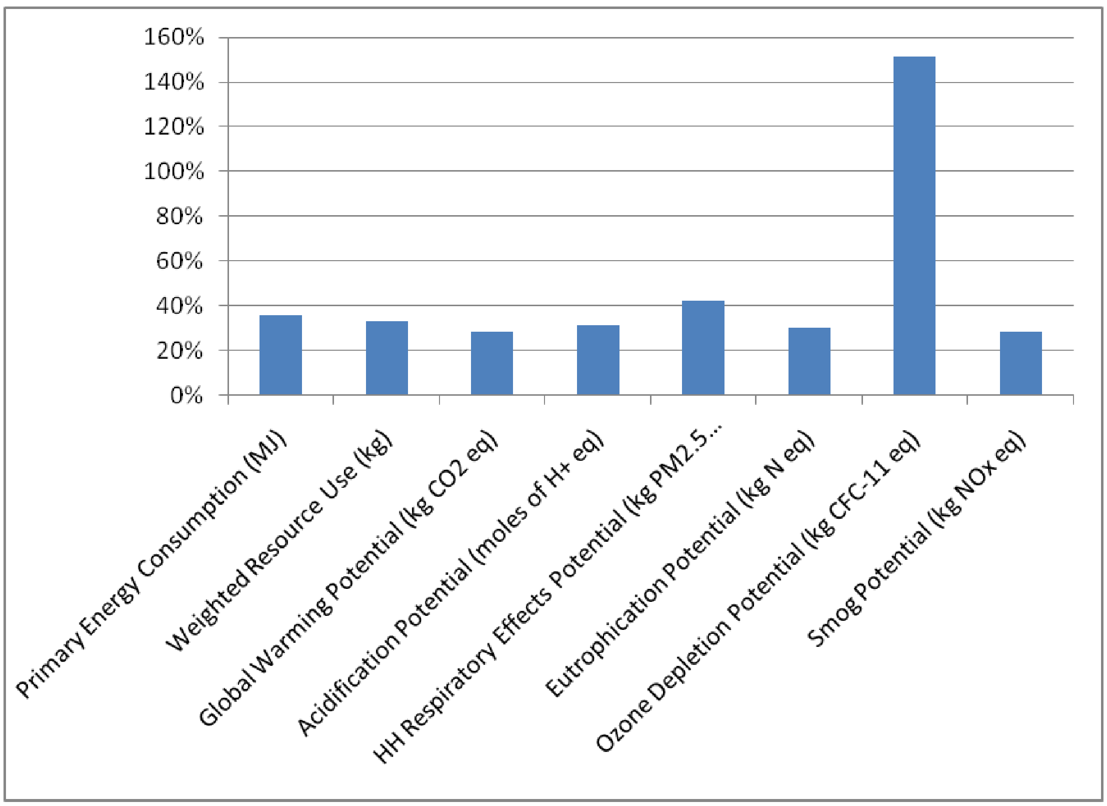


Figure 5 - Comparison of Environmental Impacts for Math building against average for other UBC buildings. Presented as percent of UBC average.

Figure 5 indicates that the environmental impacts of the Math building are much lower than the UBC building average for most impact categories. Ozone depletion potential is higher and this is found to be due to the large amount of wood in the building. In the sensitivity section, specific impacts for different materials are investigated.

The Geography building was built in the same year (1925), by the same architect, and like the Math building, is a wood frame structure with stucco. In comparing the LCA results of the Math building and the Geography building, the impacts are found to be very similar on a per square foot basis. Table 3 displays the results for the Math and Geography buildings.

Table 3 - Comparison of Summary Measures per Square Foot between two 1925 wood frame buildings, Geography and Math buildings

Impact Category	Geography	Mathematics
Primary Energy Consumption (MJ)	98.73	79.90
Weighted Resource Use (kg)	25.30	44.02
Global Warming Potential (kg CO2 eq)	5.22	5.48
Acidification Potential (moles of H+ eq)	2.66	2.57
HH Respiratory Effects Potential (kg PM2.5 eq)	0.02	0.03
Eutrophication Potential (kg N eq)	1.50E-03	2.13E-03
Ozone Depletion Potential (kg CFC-11 eq)	8.20E-08	8.96E-08
Smog Potential (kg NOx eq)	0.03	0.03

4.4 Sensitivity Analysis

Sensitivity analysis is performed to examine the sensitivity of the model to specific materials in the model. Sensitivity analysis is a valuable method to identify which materials are having the biggest impact on the results. For the sensitivity analysis for this study, the five materials deemed to be most influential on the environmental impact results were chosen and checked for sensitivity. The five materials chosen for a sensitivity analysis were cedar shiplap siding, ½ inch regular gypsum board, 4000PSI (30MPa) concrete, small dimension softwood lumber (green) and roofing asphalt. The materials were chosen on a basis of quantity in the model and strength of influence on the impacts. For example, cedar shiplap wood was chosen due to the large quantities found in the model while concrete and roofing asphalt were chosen due to their relatively large environmental impacts.

To check the materials for sensitivity, each material in turn was added to the model by a margin of 10% while keeping all other inputs the same. The modified model was then re-run in the EIE and the results were compared to the original model. This was done for each of the chosen materials. Figure 6 shows the results for this sensitivity analysis. The results are shown as a percent change in impact for each category per 10% increase in material.

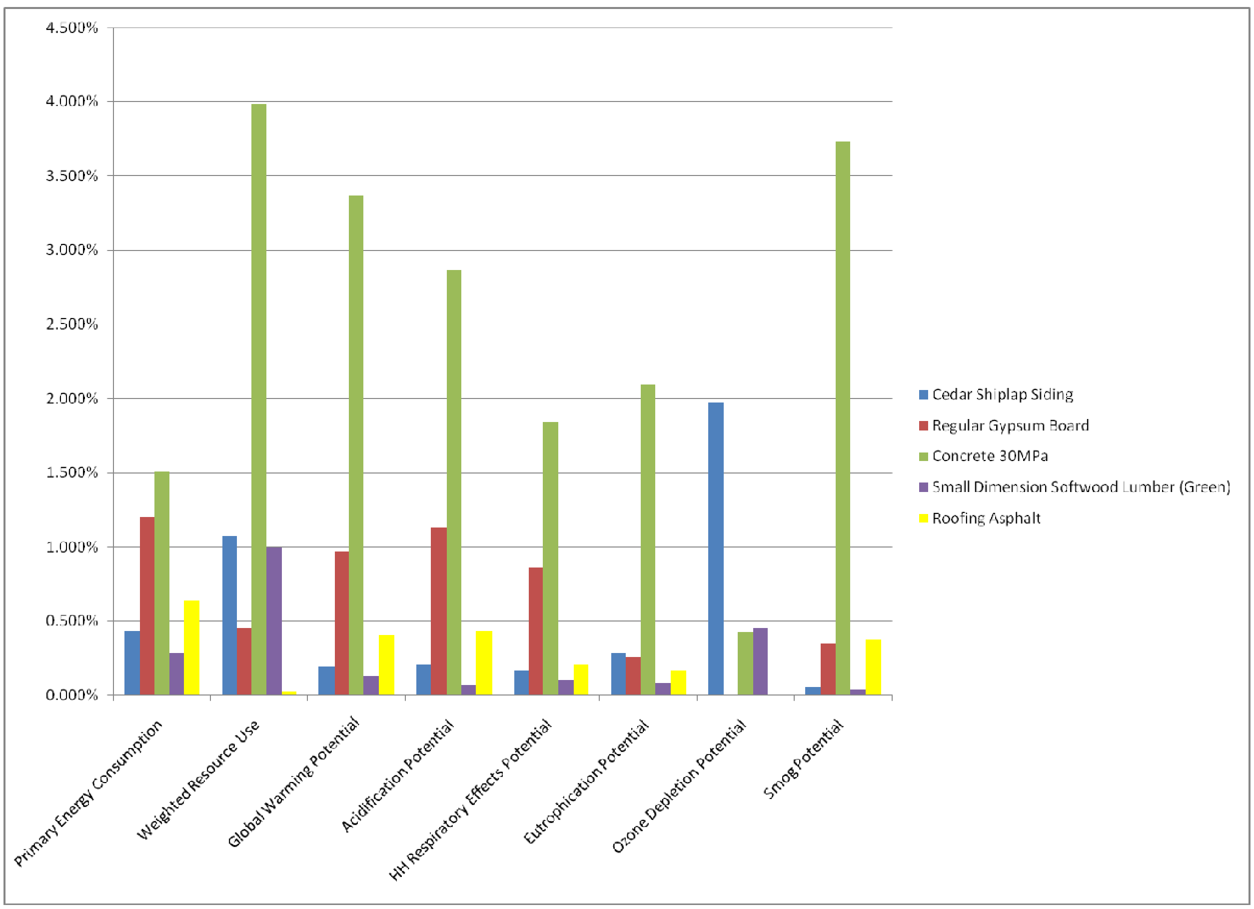


Figure 6 - Sensitivity Analysis showing percent change of each Impact category for a 10% increase in selected materials. Materials were chosen based on quantity in building and relative impact potential

As can be seen from figure 6, the model is most sensitive to concrete for all impacts except ozone depletion. This is interesting considering that this is a wood frame structure with relatively little concrete. This goes to show that concrete has a very high relative impact at the construction and manufacturing stages compared to wood. If the scope of the LCA included examining the maintenance stage the building during a 60 year lifespan, the relative impacts of concrete would decrease due to its durability as a material. Wood in the model, including both cedar shiplap siding and small dimension softwood lumber (green) show most of their impacts for weighted resource use and ozone depletion potential. It should be mentioned that small dimension softwood lumber (green) only made up approximately half of the total softwood lumber in the model and if the other softwood lumber was included for analysis, the sensitivity results would increase. Furthermore, from experience with the EIE, it is known that kiln dried lumber has approximately 3 times the energy consumption of green lumber, therefore, using green lumber to represent all softwood lumber underestimates the energy consumption. Regular gypsum board was used in the model as a surrogate material for the plaster in the building and is second only to concrete for energy consumption, global warming potential, acidification potential and respiratory effects potential. It is likely that the impacts for gypsum board are greater than plaster due to the extra manufacturing process. If this hypothesis is correct, the relatively high sensitivity of the model to these impacts implies gypsum board would lead to an overestimation for these impacts in the model. The roofing asphalt appears to most affect the primary energy consumption and global warming potential for the model. In comparison to other materials, the model appears to be less sensitive to the roofing asphalt input.

Sensitivity analysis is an especially valuable tool at the design stage of new construction or for major renovations. The results from a sensitivity analysis inform the designer which materials to be especially conscious of with respect to impacting the environmental performance of the building. The designers can then concentrate their efforts on reducing the use of materials that the building appears to be most sensitive to. Furthermore, designers can then choose to use less or more of a material in the building with confidence in the sort of environmental impacts will be caused by that material. Sensitivity analysis is especially good at highlighting the tradeoffs that exist for using different materials. For example, wood may consume less energy than concrete but the ozone depletion potential increases. This is a more informed comparison than if the only category that is being considered is embodied energy.

4.5 Uncertainty in the Impact Assessment Results

It is crucial in reviewing the results from any LCA to understand the inherent uncertainties in the study. For this study, uncertainty exists from modeling phase as well as the impact assessment phase.

In modeling the Math building, many assumptions were made. These assumptions were discussed in the takeoff section and are documented in detail in the Assumptions Document in Appendix B. These assumptions included using surrogate materials to represent real ones (eg. gypsum board for plaster) as well as assumptions regarding inputs into the EIE (eg. using roofing asphalt and aggregate stones to represent a 4 ply roof with gravel). A large source of uncertainty for this study is the assumption that building practices for the Math building are the same today as they were in 1925. The EIE is designed for todays construction methods so the estimates for type and amount of materials that go into the model are likely different than ones in the actual building. Assumptions and judgment, along with site visits were used to fill in information where the drawings were incomplete. There was also modeler error, mostly in the form of doing takeoffs from the provided drawings in OST. All of these assumptions and error in the model accumulate to cause some uncertainties in the final results of the study.

Many uncertainties arise in LCA's during the life cycle inventory collection (LCI) as well as the Impact assessment phase (LCIA). For this study, the EIE was used for the LCI and the LCIA phase of the LCA. As a result, the discussion of uncertainties for the LCI and LCIA phase are ultimately referring to the EIE outputs. . The EIE uses the Athena Life Cycle Inventory (LCI) Database. For any LCI, uncertainties exist largely from data uncertainty. To come up with the pollution and resource flows for a material, there will be variability in methods to create data, as well as data gaps requiring information to be filled in. There is also temporal and special variability in LCI data. The data is measured for a snapshot in time but it will vary with respect to time due to technological advances, and year to year variability. Spatial variability refers to the fact that manufacturing facilities in different regions will provide different results. Furthermore, data is often averaged over several factories to come up with industry average data, however, each factory may not be properly represented by this average. For the LCIA phase, the EIE uses the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2. As with any Impact Assessment database, there are uncertainties that exist in the results. One of the most prevalent sources of uncertainty for an LCIA is spatial variability for the impacts. Naturally, there are regional differences in environmental sensitivity and not all areas are affected the same. To come up with endpoint impacts such as toxicity and global warming potential, complex natural systems must be modeled with inherent uncertainty. There are uncertainties with respect to travel potential and lifetimes of pollution. Also, climate change and climate variation may affect the impacts of resource and pollution flows.

As with any LCA, there is uncertainty in this study. In order to make the most of the results and conclusions, it is important to understand these uncertainties and what is causing them. In the future, LCA's may be able to better quantify and address the inherent uncertainties in the results. Transparency in modeler methods and assumptions made throughout any study is crucial.

5 Building Performance from Energy Perspective

In this section the performance of the building from an energy perspective will be evaluated. Every building has embodied energy in the materials that go into constructing it, and it has some energy demand throughout its service life. The envelope of the structure controls the thermal performance, and ultimately, the energy efficiency of the building during its service life. The building envelope refers to the outer exposed shell of the building, including the exterior walls, windows, and roof. In addition to evaluating the performance of the current design, a suggested 'improved' design will be proposed and an energy model will be used to compare the two building designs.

5.1 Current Building Performance

Overall, there is relatively little embodied energy in Math building compared to other construction types such as concrete and steel framed construction. As built, the Math building would have likely been made with single pane windows and no insulation. Rigid board and loose insulation was only beginning to appear in the construction industry in the mid 1920's and most buildings were still being built without any (Dowling, 2009). With no insulation and single pane windows, the energy performance of the building would have been poor, especially throughout the winter months.

5.2 Improved Building Performance with Energy Model

Rather than focus on replacing and reducing the amount of material in the building in order to reduce primary energy consumption, it is recommended that better use of the cavity walls and window space be exercised to reduce the operating energy demand of the building. Since all of the exterior walls in the Math building are made with 2x6 studs, there is 5.5 inches of cavity space through all walls. Since there is stucco already on the exterior of the walls, it is not possible without major reconstruction to put rigid insulation on the exterior of the walls. It does make sense, however, to fill the wall cavities with blown in insulation. Furthermore, the performance of windows could be greatly improved if the single pane windows were replaced with a high performance glazing such as low E tin argon filled windows. For the roof, the joists are likely 2x14's since the roof has the same average span as the first floor which uses 2x14 joists. That leaves 13.5 inches of cavity space. Again the cavity space could be filled with blown in insulation. UBC building best practices now recommends buildings have walls with an R-value of 18, Roofs with an R-value of 40 and windows with an R-value of 3.2. In order to improve the Math building to attain this level of performance, it is recommended that walls be filled with 4.8 inches of blown cellulose and the roof cavity be filled in with 10.6 inches of blown cellulose. Furthermore, it is suggested that windows be upgraded to low E argon filled glazing. Table 4 on the next page shows the current and improved R values for the building. The thickness of insulation for the wall was determined based on the following equation:

$$\text{Thickness of Blown Cellulose} = \frac{Required\ R\ Value - Current\ R\ Value}{Blown\ Cellulose\ R\ Value\ Per\ Inch}$$

Table 4 - Table showing change in R-Value for 'current' and 'improved' buildings

	'Current' Building		'Improved' Building	
	Type	R-Value (ft2.degF.h/BTU)	Type	R-Value (ft2.degF.h/BTU)
Exterior Wall	No Insulation	3.50	4.8" Blown Cellulose	18.00
Window	Standard Glazing	0.91	low E tin argon filled glazing	3.45
Roof	No Insulation	3.75	10.6" Blown Cellulose	40.00

Using an Excel spreadsheet to create an energy demand model for a building, the cumulative energy demand for the 'current' and 'improved' building were calculated over time. The model took into account the average R value over the entire envelope of the structure and considered average temperature data to model exterior temperatures throughout the year. In addition, the EIE was used to calculate the embodied energy of the 'improved' and 'current' buildings and these values were used as starting point for the energy model. It was found that by adding the low E tin argon filled glazing and the insulation to the walls and roof, the embodied energy for the structure increased from 2,282,000 MJ to 2,362,000 MJ. The operating energy demand for the building, however, decreased considerably. This is shown graphically in figure 7 below.

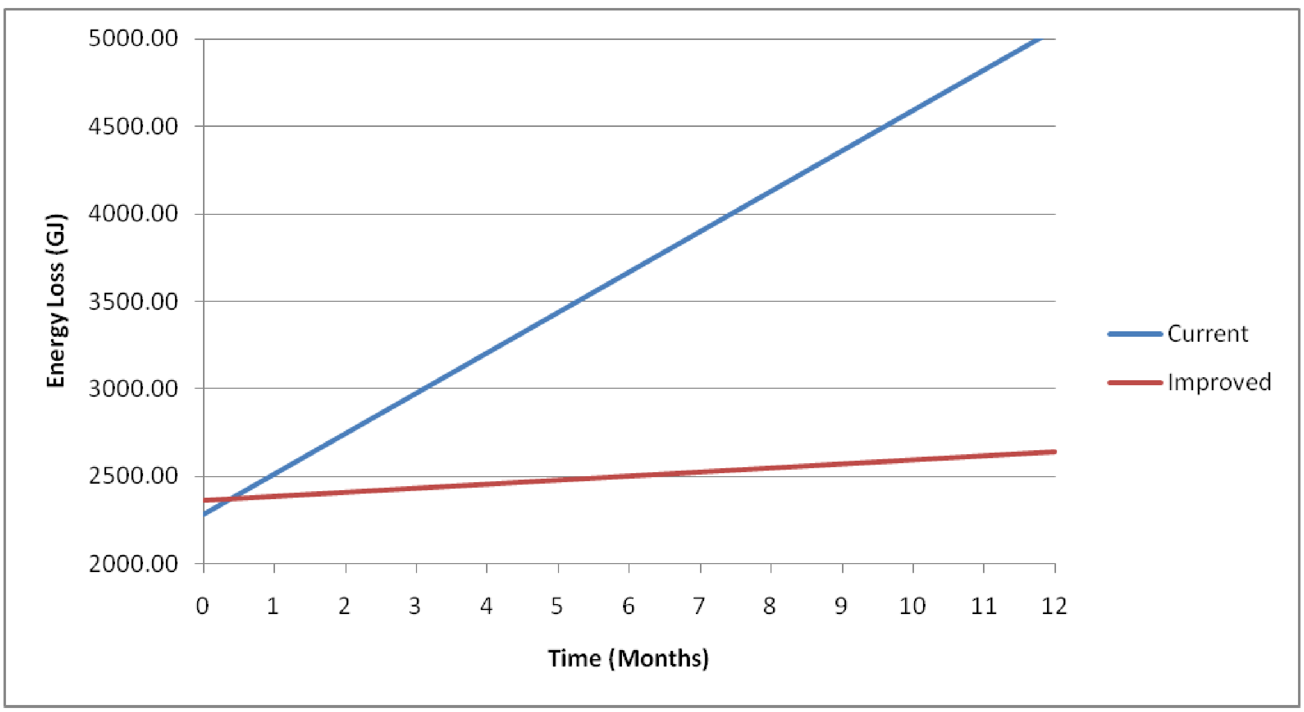


Figure 7 - Energy Loss over time for 'current' and 'improved' buildings. Note that the extra embodied energy of the 'improved' building is payed back in under 2 weeks due to improved energy efficiency

It can be seen from figure 7, that the simple energy payback period for the improved building is less than 2 weeks. Considering that this building is 85 years old, 2 weeks is a very low payback period for the structure.

It is likely that the Math building has already insulated its walls and improved the performance of its windows. If not, it is highly recommended that the suggestions above be put into action due to the large energy savings over the long term. While cost was not considered in the analysis above, it is likely that the energy cost savings over time would quickly payoff the capital investment for the windows and insulation. Blown cellulose is suggested since the walls are already built. Blown cellulose can be installed into cavity walls and roofs by drilling a small hole into the inside or outside of the wall and using equipment to blow the material in. This method saves already built structures from requiring major reconstruction in order to insulate the building.

6 Conclusion

A Life Cycle Assessment was performed for the Math building at UBC. Using the original architectural drawings as the primary data source, a material takeoff for the structure and envelope was generated for the building. Two software programs – the Athena Sustainable Material Institute's Environmental Impact Estimator (EIE) and OnCentre's OnScreen Takeoff – were used to assist in the takeoff. The EIE was then used to generate summary impact measures for various environmental impacts caused by the construction of the building.

In evaluating these results in comparison to other UBC buildings, it appears that the wood frame building produces approximately 20 to 40% of the impacts per square foot that the average UBC building produces in terms of energy consumption, resource use, eutrophication potential, acidification potential, smog potential, human health effects potential and global warming potential. It was found to produce approximately 150% of the ozone depletion potential per square foot of the average UBC building. A sensitivity analysis showed that the model was most sensitive to concrete quantities for most impacts and to wood for ozone depletion potential.

An energy model found that if blown cellulose insulation was installed into the walls and roof, and windows upgraded to low E tin argon filled glazing, the energy payback period would be less than 2 weeks and the operating energy demand would decrease substantially.

Many assumptions were required to carry out the study and all model inputs and assumptions have been documented in the inputs and assumptions documents provided in the appendicies of the report.

Bibliography

Canadian Standards Association. (2006). Environmental Management - Life Cycle Assessment - Principles and Framework. In *National Standards of Canada.*

Connaghan, J. (2009). *A Life Cycle Analysis of the Geography Building.* Vancouver: University of British Columbia.

Dowling, J. (2009). Blanketing the Home: The Use of Thermal Insulation in American Housing, 1920-1945. *APT Bulletin* , 33-39.

Norris, G. (n.d.). *The Many Dimensions of Uncertainty Analysis in LCA.* Retrieved February 25, 2010, from Athena Institute of Sustainable Materials: http://www.athenasmi.org/publications/docs/UncertaintyAnalysis_in_LCA.pdf

UBC Archives. (n.d.). *Mathematics Building*. Retrieved March 26, 2010, from University of British Columbia: http://www.library.ubc.ca/archives/bldgs/math.html

University of British Columbia. (1936). *The University of British Columbia: Twenty-First Anniversary - 1915-1936.* Retrieved March 26, 2010, from University of British Columbia: http://www.library.ubc.ca/archives/pdfs/history/ubc_21st_anniversary.pdf

Wikipedia. (2008, December 12). *Lath and Plaster*. Retrieved March 15, 2010, from Wikipedia: http://en.wikipedia.org/wiki/Lath_and_plaster

Appendix A – Inputs Document

IE Inputs Document - Math Building					
Assembly Group	**Assembly Type**	**Assembly Name**	**Input Fields**	**Input Values**	
				Known/Measured	**EIE Inputs**
Foundation					
	1.1 Concrete Slab-on-Grade				
		1.1.1 SOG_6"_Side_Entrance_Floor			
			Length (ft)	15.92	15.92
			Width (ft)	15.92	15.92
			Thickness (in)	6	4
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.2 SOG_6"_Lecture_Entrance_Floor			
			Length (ft)	16.97	16.97
			Width (ft)	16.97	16.97
			Thickness (in)	6	4
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.3 SOG_6"_Front_Entrance_Floor			
			Length (ft)	13.85	13.85
			Width (ft)	13.85	13.85
			Thickness (in)	6	4
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.4 SOG_4"_Ground_Floor_Bathroom			
			Length (ft)	23.00	23.00
			Width (ft)	23.00	23.00
			Thickness (in)	4	4
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.5 SOG_4"_First_Floor_Bathroom			

			Length (ft)	30.80	30.80
			Width (ft)	30.80	30.80
			Thickness (in)	4	4
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.6 SOG_10"_Stairs_Side_Entrance			
			Length (ft)	10.36	10.36
			Width (ft)	10.36	10.36
			Thickness (in)	10	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.7 SOG_10"_Stairs_Lecture_Entrance			
			Length (ft)	8.87	8.87
			Width (ft)	8.87	8.87
			Thickness (in)	10	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
		1.1.8 SOG_10"_Stairs_Front_Entrance			
			Length (ft)	4.76	4.76
			Width (ft)	4.76	4.76
			Thickness (in)	10	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
	1.2 Concrete Footing				
		1.2.1 Footing_S2_20"_Strip_Interior			
			Length (ft)	191	191
			Width (ft)	1.67	1.67
			Thickness (in)	8	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.2 Footing_S1_20"_Strip_Exterior			
			Length (ft)	818	818
			Width (ft)	1.67	1.67
			Thickness (in)	8	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average

			Rebar	-	#4
		1.2.3 Footing_F4_3'6"_Square			
			Length (ft)	3.5	5.68
			Width (ft)	3.5	5.68
			Thickness (in)	52	19
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.4 Footing_F3_3'8"_Square			
			Length (ft)	3.67	5.05
			Width (ft)	3.67	5.05
			Thickness (in)	36	19
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.5 Footing_F2_2'6"_Square			
			Length (ft)	19.2	19.2
			Width (ft)	19.2	19.2
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.6 Footing_F1_2'0"_Square			
			Length (ft)	14.83	14.83
			Width (ft)	14.83	14.83
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
2 Walls					
	2.1 Wood Stud				
		2.1.1 Wall_WoodStud_Vestibule_Side_Walls_2x4			
			Length (ft)	31	31
			Height (ft)	16.5	16.5
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing (in)	-	16
			Stud Type	-	green

			Wall Type	Interior	Interior
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
		2.1.2 Wall_WoodStud_Vestibule_2x4			
			Length (ft)	24	24
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	2	2
			Door Type	Solid Wood, 20% Glazing	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
		2.1.3 Wall_WoodStud_Support_Lecture_Slope_2x4			
			Length (ft)	168	168
			Height (ft)	3	3
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		2.1.4 Wall_WoodStud_Side_Entrance_2x6			
			Length (ft)	24	24
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud	2x6	2x6

			Thickness		
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	4	4
			Door Type	Solid Wood, 20% Glazing	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
		2.1.5 Wall_WoodStud_RoofStubWall			
			Length (ft)	767	767
			Height (ft)	5	5
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Exterior	Exterior
		Envelope	Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.6 Wall_WoodStud_MainStairwell_2x4			
			Length (ft)	67	67
			Height (ft)	4	4
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green

			Wall Type	Interior	Interior
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
		2.1.7 Wall_WoodStud_Lecture_Interior_Bearing_2x6			
			Length (ft)	57	57
			Height (ft)	16	16
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
		2.1.8 Wall_WoodStud_Lecture_Interior_Bearing_2x4			
			Length (ft)	21	21
			Height (ft)	22	22
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	4	4
			Door Type	Solid Wood, 20% Glazing	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
		2.1.9 Wall_WoodStud_Lecture_Exterior_2x6			

			Length (ft)	127	127
			Height (ft)	22	22
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Exterior	Exterior
		Window Opening	Number of Windows	24	24
			Total Window Area (ft2)	365	365
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.10 Wall_WoodStud_Ground_Interior_NonBearing_JanitorsCloset			
			Length (ft)	38	38
			Height (ft)	8	8
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	2	2
			Door Type	Solid Wood	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	1.5
			Category	Gypsum Board	

			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	1.5
		2.1.11 Wall_WoodStud_Ground_Interior_NonBearing_2x4			
			Length (ft)	174	174
			Height (ft)	12	12
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	8	8
			Door Type	Solid Wood	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	1.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	1.5
		2.1.12 Wall_WoodStud_Ground_Interior_Bearing_2x6			
			Length (ft)	72	72
			Height (ft)	12	12
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	0.5
		2.1.13 Wall_WoodStud_Ground_Interior_Bearing_2x4			
			Length (ft)	634	634
			Height (ft)	12	12
			Sheathing Type	none	none

			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	26	26
			Door Type	Solid Wood	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	0.5
		2.1.14 Wall_WoodStud_Ground_Exterior_2x6+2x4			
			Length (ft)	195	195
			Height (ft)	13	13
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Exterior	Exterior
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Window Opening	Number of Windows	34	34
			Total Window Area (ft2)	563	563
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	5.5
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh

			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.15 Wall_WoodStud_Ground_Exterior_2x6			
			Length (ft)	477	477
			Height (ft)	13	13
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Exterior	Exterior
		Door Opening	Number of Doors	4	4
			Door Type	Solid Wood	Solid Wood
		Window Opening	Number of Windows	72	72
			Total Window Area (ft2)	1032	1032
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.16 Wall_WoodStud_Front_Entrance_2x4			
			Length (ft)	7	7
			Height (ft)	9.5	9.5
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16

			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	2	
			Door Type	Solid Wood, 20% Glazing	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.17 Wall_WoodStud_First_Interior_NonBearing_2x4			
			Length (ft)	294	294
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	11	11
			Door Type	Solid Wood	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	0.5
		2.1.18 Wall_WoodStud_First_Interior_Bearing_2x6			
			Length (ft)	44	44
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16

			Stud Type	-	green
			Wall Type	Interior	Interior
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	0.5
		2.1.19 Wall_WoodStud_First_Interior_Bearing_2x4			
			Length (ft)	529	529
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Door Opening	Number of Doors	20	20
			Door Type	Solid Wood	Solid Wood
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	0.5
		2.1.20 Wall_WoodStud_First_Interior_Bathroom_Double2x4			
			Length (ft)	81	81
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green

			Wall Type	Interior	Interior
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness	-	0.5
		2.1.21 Wall_WoodStud_First_Exterior_2x6+2x4			
			Length (ft)	208	208
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Exterior	Exterior
			Sheathing Type	none	none
			Stud Thickness	2x4	2x4
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		Window Opening	Number of Windows	40	40
			Total Window Area (ft2)	599	599
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.22 Wall_WoodStud_First_Exterior_2x6			

			Length (ft)	560	560
			Height (ft)	11	11
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green
			Wall Type	Exterior	Exterior
		Window Opening	Number of Windows	76	76
			Total Window Area (ft2)	1016	1016
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		Envelope	Category	Gypsum Board	
			Material	Lath and Plaster	1/2" Regular Gypsum Board
			Thickness (in)	-	0.5
			Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		2.1.23 Wall_WoodStud_CeilingLectureRoom_2x6			
			Length (ft)	45	45
			Height (ft)	56.33	56.33
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	16	16
			Stud Type	-	green
			Wall Type	Interior	Interior
		2.1.24 Wall_WoodStud_Basement_2x6			
			Length (ft)	347	347
			Height (ft)	5	5
			Sheathing Type	none	none
			Stud Thickness	2x6	2x6
			Stud Spacing	-	16
			Stud Type	-	green

			Wall Type	Exterior	Exterior
		Window Opening	Number of Windows	10	10
			Total Window Area (ft2)	59	59
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		Envelope	Category	Cladding	
			Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
			Thickness	-	-
			Category	Cladding	
			Material	Cedar Shiplap	Cedar Shiplap Siding
			Thickness	-	-
	2.2 Cast-In-Place				
		2.2.1 Wall_Cast-In-Place_W2_8"_Internal			
			Length (ft)	190	190
			Height (ft)	4	4
			Thickness (in)	8	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	Average
			Rebar	-	#5
		2.2.2 Wall_Cast-In-Place_W1_10"_External			
			Length (ft)	818	1022
			Height (ft)	4.5	4.5
			Thickness (in)	10	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	Average
			Rebar	-	#5
		Window Opening	Number of Windows	4	4
			Total Window Area (ft2)	19	19
			Frame Type	Wood Frame	Wood Frame
			Glazing Type	-	Standard Glazing
		2.2.3 Wall_Cast-In-Place_Entrance			
			Length (ft)	14.67	14.67
			Height (ft)	14	14
			Thickness (in)	12	12

			Concrete (psi)	-	4000
			Concrete flyash %	-	Average
			Rebar	-	#5
3 Floors					
	3.1 Wood Joist				
		Floor_WoodJoist_Lecture_Sloped			
			Floor Width (ft)	340	340
			Span (ft)	6	6
			Decking Type	none	none
			Live load (psf)	45	45
			Decking Thickness	none	none
			Category	Cladding	
			Material	Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		Floor_WoodJoist_Lecture_Flat			
			Floor Width (ft)	254	254
			Span (ft)	10	10
			Decking Type	none	none
			Live load (psf)	45	45
			Decking Thickness	none	none
			Category	Cladding	
			Material	Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		Floor_WoodJoist_GroundFloor			
			Floor Width (ft)	1215	1215
			Span (ft)	10	10
			Decking Type	none	none
			Live load (psf)	45	45
			Decking Thickness	none	none
			Category	Cladding	
			Material	Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		Floor_WoodJoist_FirstFloor			
			Floor Width	-	833

			(ft)		
			Span (ft)	21.8	14.96
			Decking Type	none	none
			Live load (psf)	45	45
			Decking Thickness	none	none
			Category	Cladding	
			Material	Shiplap	Cedar Shiplap Siding
			Thickness	-	-
4 Roofs					
	4.1 Wood Joist				
		4.1.1 Roof_WoodJoist_4-Ply_Truss_Lecture_Room			
			Roof Width (ft)	182.7	182.7
			Span (ft)	14.5	14.5
			Decking Type	-	None
			Live load (psf)	45	45
			Decking Thickness	-	None
		Envelope	Category	Roofing	Roofing
			Material	4 ply roof	roofing asphalt
			Thickness (in)	-	-
			Category	roofing envelopes	roofing envelopes
			Material	gravel	ballast
			Thickness (in)	-	-
			Category	Cladding	
			Material	Shiplap	Cedar Shiplap Siding
			Thickness	-	-
		4.1.2 Roof_WoodJoist_4-Ply_Joist_Main_Bldg			
			Roof Width (ft)	868.4	868.4
			Span (ft)	14.96	14.96
			Decking Type	-	None
			Live load (psf)	45	45
			Decking Thickness	-	None
			Category	Roofing	Roofing
			Material	4 ply roof	roofing asphalt
			Thickness (in)	-	-

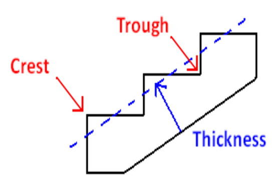
		Envelope	Category	roofing envelopes	roofing envelopes
			Material	gravel	ballast
			Thickness (in)	-	-
			Category	Cladding	
			Material	Shiplap	Cedar Shiplap Siding
			Thickness	-	-
5 Extra Basic Materials					
	5.1 Wood				
		Total	Softwood Lumber (large, green) (Mbfm)	15.08	15.08
		Total	Softwood Lumber (small, green) (Mbfm)	15.90	15.90
		5.1.1 - XBM_Foundation_Girder_Wood_8x12			
			Softwood Lumber (large, green) (Mbfm)	0.37	0.37
		5.1.2 - XBM_Foundation_Girder_Wood_8x10			
			Softwood Lumber (large, green) (Mbfm)	6.57	6.57
		5.1.3 - XBM_Foundation_Girder_Wood_6x8			
			Softwood Lumber (large, green) (Mbfm)	0.91	0.91
		5.1.4 - XBM_Foundation_Girder_Wood_6x10			
			Softwood Lumber (large, green) (Mbfm)	0.78	0.78
		5.1.5 - XBM_Foundation_Column_Wood_8X8			

			Softwood Lumber (large, green) (Mbfm)	2.24	2.24
		5.1.6 - XBM_Foundation_Column_Wood_8x10			
			Softwood Lumber (large, green) (Mbfm)	0.13	0.13
		5.1.7 - XBM_Foundation_Column_Wood_6X8			
			Softwood Lumber (large, green) (Mbfm)	0.56	0.56
		5.1.8 - XBM_Foundation_Column_Wood_6X6			
			Softwood Lumber (large, green) (Mbfm)	0.04	0.04
		5.1.9 - XBM_Foundation_Column_Wood_10X10			
			Softwood Lumber (large, green) (Mbfm)	0.89	0.89
		5.1.10 XBM_Truss_Lecture_Room			
			Softwood Lumber (large, green) (Mbfm)	2.58	2.58
		5.1.11 XBM_Stairs_Wood_Main			
			Softwood Lumber (Small, kiln dried) (Mbfm)	1.01	1.01
		5.1.12 XBM_Stairs_Wood_Entrance_landing-2nd			
			Softwood Lumber (Small, green)	0.16	0.16

			(Mbfm)		
		5.1.13 XBM_Stairs_Wood_Entrance_1st-landing			
			Softwood Lumber (Small, green) (Mbfm)	0.33	0.33
		5.1.14 XBM_Cedar_Laths			
			Softwood Lumber (Small, green) (Mbfm)	14.39	14.39
	5.2 Steel				
		5.2.1 – XBM_Truss_Lecture_Room			
			Rebar Rod Light Sections (Tons)	0.27	0.27
			Cold Rolled Steel (Tons)	0.87	0.87

Appendix B – Assumptions Document

IE Input Assumptions Document - AERL			
Assembly Group	**Assembly Type**	**Assembly Name**	**Specific Assumptions**
1 Foundation	For the Impact Estimator, SOG inputs are limited to being either a 4" or 8" thickness. Since some of the actual SOG thicknesses for the Math building were not exactly 4" or 8" thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. For purposes of calculating Length and Widths of SOG's all areas are square rooted to give the equivalent square area dimensions. This allows irregular shapes to be easily inputed into the EIE. The Impact Estimator limits the thickness of footings to be between 7.5" and 19.7" thick. Adjustments were made where necessary to make the thicknesses fit within these constraints while maintaining the same total volume. Concrete properties are not provided in the drawing set. Concrete strength is assumed to be 4000PSI and flyash content was assumed to average.		
	1.1 Concrete Slab-on-Grade		
		1.1.1 SOG_6"_Side_Entrance_Floor	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[(169 x (6"/12))/(4"/12)] = 15.92ft
		1.1.2 SOG_6"_Lecture_Entrance_Floor	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[(192 x (6"/12))/(4"/12)] = 16.97ft
		1.1.3	The area of this slab had to be adjusted so that the thickness fit into

		SOG_6"_Front_Entrance_Floor	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[(128 x (6”/12))/(4”/12)] = 13.85ft
		1.1.4 SOG_4"_Ground_Floor_Bathroom	The thickness for this floor was available for the EIE input. Just had to squareroot the area takeoff to get an input length and width. Length=Width= SQRT(Area)= =SQRT(529)=23ft
		1.1.5 SOG_4"_First_Floor_Bathroom	The thickness for this floor was available for the EIE input. Just had to squareroot the area takeoff to get an input length and width. Length=Width= SQRT(Area)= =SQRT(949)=30.8ft
		1.1.6 SOG_10"_Stairs_Side_Entrance	The thickness of the stairs was assumed to be the same as for the front entrance stairs. The thickness of the stairs was taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. Drawing 518-06-008 provides a clear view of a section of the stairs. Onscreen Takeoff was used to get the plan view area, and a slope and thickness were then applied to get the volume of the stairs. Using 8" thickness, the following calculation gave the length and width: Length = Width= SQRT(Volume/(8in/12in/ft)) =SQRT(161ft^3/(8/12))=10.36ft
		1.1.7 SOG_10"_Stairs_Lecture_Entrance 	The thickness of the stairs was assumed to be the same as for the front entrance stairs. The thickness of the stairs was taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. Drawing 518-06-008 provides a clear view of a section of the stairs. Onscreen Takeoff was used to get the plan view area, and a slope and thickness were then applied to get the volume of the stairs. Using 8" thickness, the following calculation gave the length and width: Length = Width= SQRT(Volume/(8in/12in/ft)) =SQRT(118ft^3/(8/12))=8.87ft
		1.1.8 SOG_10"_Stairs_Front_Entrance	The thickness of the stairs was taken as the approximate depth

			view area, and a slope and thickness were then applied to get the volume of the stairs. Using 8" thickness, the following calculation gave the length and width: Length = Width= SQRT(Volume/(8in/12in/ft)) =SQRT(34ft^3/(8/12))=4.76ft
	1.2 Concrete Footing		
		1.2.1 Footing_S2_20"_Strip_Interior	Rebar type not given. Assume rebar to be #4 Dimensions of strip footings given in drawings 518-06-009 and 518-06-008
		1.2.2 Footing_S1_20"_Strip_Exterior	Rebar type not given. Assume rebar to be #4 Dimensions of strip footings given in drawings 518-06-009 and 518-06-008
		1.2.3 Footing_F4_3'6"_Square	This Footing is a large bulk concrete footing supporting posts which support the Truss's spanning the lecture room. There are 3 footings. The dimensions were taken from drawing 518-06-008. To accomodate the maximum footing thickness input that can be put into the EIE, the following calculation was done: Length=Width=SQRT(Volume/Input Thickness) =SQRT((3 footingsx3'6"x3'6"x4'2")/(19"/12"/ft))=9.83ft Type of Rebar used was not given. Assumed #4 rebar
		1.2.4 Footing_F3_3'8"_Square	This Footing is a large bulk concrete footing supporting posts which support the Truss's spanning the lecture room. There are 3 footings. The dimensions were taken from drawing 518-06-008. To accomodate the maximum footing thickness input that can be put into the EIE, the following calculation was done: Length=Width=SQRT(Volume/Input Thickness) =SQRT((3 footingsx3'8"x3'8"x3')/(19"/12"/ft))=8.74ft Type of Rebar used was not given. Assumed #4 rebar
		1.2.5 Footing_F2_2'6"_Square	There are 59 of these footings. Thickness assumed to be same as ones shown in drawing 518-06-008. In order to input into EIE, an equivalent area square footing was calculated with the length and width being inputed. The calculation is as follows: Length=Width=SQRT(#footingsxArea/footing) =SQRT(59x(2'6"x2'6"))=19.2ft

			Type of Rebar used was not given. Assumed #4 rebar
		1.2.6 Footing_F1_2'0"_Square	There are 55 of these footings. Thickness assumed to be same as ones shown in drawing 518-06-008. In order to input into EIE, an equivalent area square footing was calculated with the length and width being inputed. The calculation is as follows: Length=Width=SQRT(#footingsxArea/footing) =SQRT(55x(2'x2'))=14.83ft Type of Rebar used was not given. Assumed #4 rebar

2 Walls	All Walls were modeled in On Screen Takeoff using the linear condition. WoodStud Walls were assumed to be interior or exterior based on if they were in contact with the elements. Stud type was not known, assumed to be green wood. Stud spacing was not specified for majority of walls and was assumed to be 16in. Lath and Plaster was used to finish all interior walls. Due to IE limitations, Lath and plaster was modeled as 1/2 in of regular gypsum and cedar laths which are accounted for with an additional condition in XBM's. Some doors had 20% glazing, and were modeled as solid wood due to EIE limitations. All doors assumed to be solid wood. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not, although all are modelled as operable. For exterior envelope system, drawings show that 3 coat stucco sits overtop chicken wire, cedar laths, vertical battens, paper, and shiplap. In the EIE, this envelope system was modeled as stucco over metal mesh and cedar shiplap siding. Shiplap is assumed to be cedar because all lath material used in building is cedar. Vertical battens are assumed to be negligible and paper cannot be modeled in EIE. Cast in Place walls can only be inputed into the EIE as 8in or 12in thick. Calculations were made to adjust walls to fit within this constraint by changing the length of the wall. No rebar was specified for the walls and was assumed to be #5. Concrete strength was not specified for the walls and was assumed t be 4000PSI.		
	2.1 WoodStud		
		2.1.1 Wall_WoodStud_Vestibule_Side_Walls_2x4	Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Height of wall estimated from drawing 518-06-008
		2.1.2 Wall_WoodStud_Vestibule_2x4	Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors have 20% glazing, modeled as solid wood due to EIE limitations

		2.1.3 Wall_WoodStud_Support_Lecture_Slope_2x4	These walls are used to support the sloped bleachers in the lecture room. Assumed no envelope. Wall Height is approximated from averaging 3 such walls as shown in drawing 518-06-008
		2.1.4 Wall_WoodStud_Side_Entrance_2x6	One side of wall is has lath and plaster, one side butts up to exterior wall, and has no envelope material. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors have 20% glazing, modeled as solid wood due to EIE limitations
		2.1.5 Wall_WoodStud_RoofStubWall	This roof stub wall is modelling the exterior wall that juts up above the first floor ceiling and sticks up above the flat roof. The height of 5ft is estimated from drawings 518-06-007 and 518-06-008. Stucco is modelled on both sides of wall. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding. Shiplap assumed to be cedar because all lath material in building is cedar.
		2.1.6 Wall_WoodStud_MainStairwell_2x4	This wall was modeled to take into account the side of the main stair structure as well as the the stub wall that serves as a guard wall around the top of the stairs. One side has lath and plaster. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.7 Wall_WoodStud_Lecture_Interior_Bearing_2x6	Height is 16ft and is floor to ceiling height. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's

		2.1.8 Wall_WoodStud_Lecture_Interior_Bearing_2x4	Height is 22ft and is floor to underside of roof height. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors have 20% glazing, modeled as solid wood due to EIE limitations
		2.1.9 Wall_WoodStud_Lecture_Exterior_2x6	Height is 22ft and is floor to underside of roof height. One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.10 Wall_WoodStud_Ground_Interior_NonBearing_JanitorsCloset	Height taken from drawing 518-06-037 Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.11 Wall_WoodStud_Ground_Interior_NonBearing_2x4	Height taken as floor to ceiling height for ground floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.12 Wall_WoodStud_Ground_Interior_Bearing_2x6	Height taken as floor to ceiling height for ground floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's

		2.1.13 Wall_WoodStud_Ground_Interior_Bearing_2x4	Height taken as floor to ceiling height for ground floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.14 Wall_WoodStud_Ground_Exterior_2x6+2x4	The height of this wall is taken as the floor to floor height for the ground floor. The reason it was taken as floor to floor is to account for the potentially high impact stucco material in between floors on the exterior. The floors, as a result, are only modelled to the inside of exterior walls. This wall is made up of a 2x6 wall and a 2x4 wall on the inside of it. The 2x6 wall is modelled as exterior and the 2x4 wall is modelled as interior One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.15 Wall_WoodStud_Ground_Exterior_2x6	The height of this wall is taken as the floor to floor height for the ground floor. The reason it was taken as floor to floor is to account for the potentially high impact stucco material in between floors on the exterior. The floors, as a result, are only modelled to the inside of exterior walls. One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. All doors assumed to solid wood. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.

		2.1.16 Wall_WoodStud_Front_Entrance_2x4	Height of wall estimated from drawing 518-06-008 One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Doors have 20% glazing, modelled as solid wood doors due to EIE limitations
		2.1.17 Wall_WoodStud_First_Interior_NonBearing_2x4	Height taken as floor to ceiling height for First floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.18 Wall_WoodStud_First_Interior_Bearing_2x6	Height taken as floor to ceiling height for First floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.19 Wall_WoodStud_First_Interior_Bearing_2x4	Height taken as floor to ceiling height for First floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.20 Wall_WoodStud_First_Interior_Bathroom_Double2x4	This wall is made up of 2 2x4 wood stud walls with a cavity in the middle for venting and plumbing Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's

		2.1.21 Wall_WoodStud_First_Exterior_2x6+2x4	Height is floor to ceiling height for first floor. The roof stub wall accounts for wall above this wall. This wall is made up of a 2x6 wall and a 2x4 wall on the inside of it. The 2x6 wall is modelled as exterior and the 2x4 wall is modelled as interior One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.22 Wall_WoodStud_First_Exterior_2x6	Height is floor to ceiling height for first floor. The roof stub wall accounts for wall above this wall. One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.23 Wall_WoodStud_CeilingLectureRoom_2x6	This wall is modelling the ceiling that is above the lecture room. The ceiling is not structural, stud spacing and stud thickness are known. No envelope is modelled since the System Boundary of this LCA does not include ceiling finishing material. Single wall with length being the length of the lecture room and a height the width of the lecture room is modelled
		2.1.24 Wall_WoodStud_Basement_2x6	This wall extends from the top of the concrete foundation wall to the ground floor for the back (West) half the building The wall height is 5 feet and is approximated from drawings 518-06-007 and 518-06-008 Stucco on exterior and lath and plaster on the inside Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum

			board.
	2.2 Cast-In-Place		
		2.2.1 Wall_Cast-In-Place_W2_8"_Internal	Height was not explicitly shown in any of the drawings. A height of 4ft was estimated from examining topography as well as stair and floor heights above the foundation walls. No rebar specified, assumed to be #5 No flyash specified, assumed to be average. No strength specified, assumed to be 4000PSI
		2.2.2 Wall_Cast-In-Place_W1_10"_External	Height was estimated by dividing the total external wall area by the total length of the wall. This will give height. Height was found to be: Height=External Wall Area/Length=4407/818=4.5ft The EIE can only input walls 8 or 12" thick. In order to input the 10" wall as an 8" wall, the following calculation was done: Input Length=Total Volume/(Height x Input Thickness)= =(Actual Length x Height x Actual Thickness)/(Height x Input Thickness) =(818ft x 4.5ft x (10/12)ft)/(4.5ft x (8/12)ft)= 1022ft No rebar specified, assumed to be #5 No flyash specified, assumed to be average. No strength specified, assumed to be 4000PSI Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.

		2.2.3 Wall_Cast-In-Place_Entrance	Volume for the Concrete Entrance Structure was found by taking details from drawing 518-06-009 and adding up simplified geometric segments to get the overall volume. The volume was found to be 206 ft^3. Due to the input constraints for thickness in the EIE, the wall was inputed as having a 12in thckness and the linear takeoff in OnScreen was found to be 14ft 8in. The height was then calculated to be: Height=Volume/(Input thickness x Length)=206ft/(1ft x 14.67ft)= 14ft No rebar specified, assumed to be #5 No flyash specified, assumed to be average. No strength specified, assumed to be 4000PSI

3 Floors	For each floor, an average span was found for a floor by finding a weighted average span. This can most easily be explained by showing the equation for the calculation as: Average Span=$(\sum\_(\text{floor area})_i \times (\text{floor span})_i)/(\sum\_(\text{floor area})_i)$ The EIE has a maximum span input of 14.96ft. For Spans that were larger than this, 14.96ft was used. Cedar Shiplap is added as decking material. Drawing 518-06-006 shows that shiplap is used as decking material. Cedar Shiplap is thus added as cladding in the envelope. Cedar is assumed because all the lath material for the building is cedar. The Floor dimension inputs for the EIE are span and width. An area was found in OnScreen for each floor. Input width was found for each floor by dividing the total floor area by the input span. Calculations are shown for each floor condition. The Live Load was not given in the Drawings. In the LCA report for the Geography building, which was built in the same year and by the same architect, it states, "An assumed live load of 45psf was used based on drawing 401-07-001, a list of specifications from a 2004 renovation." Based on this, an assumed live load of 45PSF was used for all floors		
	3.1 Wood Joist		
		3.1.1 Floor_WoodJoist_Lecture_Sloped	This floor refers to the sloped bleachers in the lecture room. It is assumed that a wood joist floor reasonably approximates the material required for a stepped bleacher structure. The span for this floor area was approximated as 6ft from examination of drawing 518-06-008. The input width for the EIE is calculated as: Input Width= Total Area/Span =2039ft/6ft=340ft
		3.1.2 Floor_WoodJoist_Lecture_Flat	The average span was found to be 10ft. The input width for the EIE is calculated as: Input Width= Total Area/Span =2538ft/10ft=254ft

		3.1.3 Floor_WoodJoist_GroundFloor	The average span was found to be 10ft. The input width for the EIE is calculated as: Input Width= Total Area/Span =12148ft/10ft=1215ft
		3.1.4 Floor_WoodJoist_FirstFloor	The average span was found to be 21.8ft The max span that can be inputed into the EIE is 14.96ft. 14.96ft was used for the span. The input width for the EIE is calculated as: Input Width= Total Area/Span =12465ft/14.96ft=833ft

4 Roofs	For each roof, an average span was found for a floor by finding a weighted average span. This can most easily be explained by showing the equation for the calculation as: Average Span=(∑_(floor area)i×(floor span)i)/(∑_(floor area)i) The EIE has a maximum span input of 14.96ft. For Spans that were larger than this, 14.96ft was used. The roof has a small slope to it but it is modelled as being flat. Shiplap was added as the decking material. Drawing 518-06-006 shows that shiplap is used as decking material. Shiplap is thus added as cladding in the envelope. From Drawing 518-06-006 we know it is a 4 ply felt and gravel roof. Asphalt roofing and an aggregate ballast was used in the EIE. It is assumed that there is no insulation in the roof. The Live Load was not given in the Drawings. In the LCA report for the Geography building, which was built in the same year and by the same architect, it states, "An assumed live load of 45psf was used based on drawing 401-07-001, a list of specifications from a 2004 renovation." Based on this, an assumed live load of 45PSF was used for the roofs.		
	4.1 Wood Joist		
		4.1.1 Roof_WoodJoist_4-Ply_Truss_Lecture_Room	The average span was found to be 14.5ft. The input width for the EIE is calculated as: Input Width= Total Area/Span =2649ft/14.5ft=182.7ft

		4.1.2 Roof_WoodJoist_4-Ply_Joist_Main_Bldg	The average span was found to be 21.8ft. The max span that can be inputed into the EIE is 14.96ft. 14.96ft was used for the span. The input width for the EIE is calculated as: Input Width= Total Area/Span =12991ft/14.96ft=868.4ft

5 Extra Basic Materials										
	5.1 Wood									
		5.1.1 - 5.1.9 - Girders and Columns								
			All of the calculations for the volume of wood in the columns and girders is shown in the table to the right. The actual wood used for the columns and girders is not specified in the drawings. The wood is modelled as large dimension lumber. This is believed to be a better representation of the beams and columns than glulam beams, which is the only other reasonable input from the EIE. For the 8x8, 8x10 and 6x8 columns, there were no drawings specifying heights. Drawings 518-06-008 and 518-06-007 were used to estimate the column heights based on the difference between foundation and floor height. Drawing 518-07-001	**Type**	**Count**	**Height(ft)**	**Total Linear Length (ft)**	**X sec Area (ft^2)**	**Volume (ft^3)**	**Volume (MBFM)**
				Girder 8x12	-	-	46	0.67	30.67	0.37
				Girder 8x10	-	-	986	0.56	547.78	6.57
				Girder 6x8	-	-	227	0.33	75.67	0.91
				Girder 6x10	-	-	156	0.42	65.00	0.78
				Column 8x8	70	6	420	0.44	186.67	2.24
				Column 8x10	4	5	20	0.56	11.11	0.13
				Column 6x8	28	5	140	0.33	46.67	0.56
				Column 6x6	12	1.17	14.04	0.25	3.51	0.04
				Column 10x10	6	17.83	106.98	0.69	74.29	0.89
									Total =	12.50

			had all girder lengths shown.							

		5.1.10 XBM_Truss _Lecture_Room	All of the calculations for the volume of wood in Truss is shown in the table to the right. The actual wood used for the Truss members is not specified in the drawings. The wood is modelled as large dimension lumber. This is believed to be a better representation of the beams and columns than glulam beams, which is the only other reasonable input from the EIE. The takeoff to right is for one truss. There are 3 total trusses.	**Wood Each Truss**						
				Section	**Type**	**Length (ft)**	**X Sec Area (ft^2)**	**Volume (MBFM)**		
				Bottom Chord	8x10	46	0.56	0.31		
				Top Chord	8x10	34	0.56	0.23		
				Top Chord	2x10	46	0.14	0.08		
				Diagonal	8x10	13.33	0.56	0.09		
				Diagonal	8x8	13.33	0.44	0.07		
				Diagonal	6x8	13.33	0.33	0.05		
				Diagonal	4x6	13.33	0.17	0.03		
				Strut	2x8	9	0.11	0.01		
							Total=	**0.86**		

		5.1.11 - 5.1.13 - Wood Stairs	The takeoff for one of the main stairs (5.1.11 XBM_Stairs_Wood_Main) is shown to the right. The takeoff is done for one stair from the main stairwell, shown in detail in drawing 518-06-037. The total takeoff is estimated by multiplying the number of stairs by the value for one stair. For all other wood stairs in the building, it is assumed they are built the same way and the same takeoff was used. The takeoff is for stairs 6ft wide. For other stairs the takeoff per stair was adjusted for different widths.	**Wood Per Stair**						
				#	**Section**	**Type**	**Length (ft)**	**X Sec Area (ft^2)**	**Volume (MBFM)**	
				4	Carriage	2x12	1	0.166667	0.008	
				1	Step	2x12	6	0.166667	0.012	
				1	Step Front	1x6	6	0.041667	0.003	
								Total	**0.023**	

			Thus, Volume(Stair_Entrance_1st-landing)=Volume(Main Stair)*Width(Entrance Stair)/Width(Main Stair) For Stair_Entrance_1st-landing (4 feet wide), Volume=0.023MBFM/stair x 4ft/6ft x 7 stairs = 0.33MBFM The wood type is not specified in the drawings and is assumed to be small dimension lumber.							
		5.1.14 XBM_Cedar_Laths	To calculate laths, the total net wall area which has lath and plaster was measured in onscreen takeoff. This is done by adding an additional surface area quantity calculation for all lath and plaster walls in Onscreen. Surface area of both sides was calculated for walls with two sided lath and plaster. Windows and door area were subtracted from the gross wall area to give the net wall area. Laths are assumed to be 1/4in thick, 2in wide and seperated by 1/4in. This means that 8/9 of the wall is covered in laths. Thus 8/9 of the net wall area is assumed to be covered in solid laths. The Volume calcualtion to the right is based on this assumption. Although it is known that the laths are cedar, it is thought to be more accurate to model the lath as small dimension lumber than the cedar siding. The cedar siding does not specify a thickness, and so this way the volume takeoff is more accurately inputed into the EIE.	**Wall Area(ft^2)**	**Window Area (ft^2)**	**Door Area (ft^2)**	**Net Area (ft^2)**	**Lath Area (8/9 of Net Area)**	**Lath Volume (MBFM)**	
				68925	3634	516	64775	57577	14.39	

	5.2 Steel							
		5.2.1 - XBM_Steel_ First Floor Truss	The takeoff for the steel used in the truss is shown to the right. The takeoff was divided into two parts: plate steel inputed as cold rolled steel, and rod sections inputed as rebar rod light sections The takeoff was based on details provided in drawing 518-06-008	**Truss Steel Rods**				
				Per Truss				
				Type	**Length (ft)**	**X Sec Area (ft^2)**	**Volume (ft^3)**	**Weight (tons)**
				1 5/8" rod	12.00	0.01	0.17	0.04
				1 3/8" rod	12.00	0.01	0.12	0.03
				7/8" rod	12.00	0.00	0.05	0.01
				3/4" rod	6.00	0.00	0.02	0.00
							Total=	**0.09**
				Steel Truss Plates				
				Per Truss				
				#	**Type**	**Length (ft)**	**Volume (ft^3)**	**Weight (tons)**
				18.00	4" x 6" x 3/8"	-	0.19	0.05
				-	2" x 8"	9.00	1.00	0.25
							Total=	**0.29**