A Life Cycle Analysis of the Geography Building

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Abstract

This life cycle analysis was performed on the UBC Geography Building, a 51883sf wood-frame academic building built in 1924, for the purpose of establishing a materials inventory and environmental impact reference to be applied in the assessment of potential upgrades. It was also completed simultaneously with 12 other academic and residential buildings at UBC for environmental performance comparisons across UBC buildings over time and between different materials, structural types and building functions.

The building was modeled with On Center's On-Screen Takeoff and Athena Sustainable Materials Institute's Impact Estimator using architectural drawings provided. From this model, a Bill of Materials was determined, showing that the largest quantities of material were gypsum board, softwood plywood, 6mil polyethylene, cedar wood shiplap, and stucco.

The determined summary measures were then compared to the average UBC academic building. It was found that the primary energy consumption, weighted resource use, global warming potential, acidification potential, human health respiratory effects potential, eutrophication potential, and smog potential ranged from 6.4%-30.0% of the average building, and the ozone depletion potential around 2 times the average building. It was determined through sensitivity analysis that the ozone depletion potential was high in comparison due to the amount of plywood.

Finally, the building performance was modeled using R-values for the windows, exterior walls and roof. It was determined that adding 4.5" and 3.5" of polyisocyanurate insulation to the roof and exterior walls, respectively, and replacing the windows with low E tin argon filled glazing would have a 1.55 year energy payback period.

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1 Introduction

The Geography Building, located at 1984 West Mall, Vancouver on the University of British Columbia campus, was constructed in 1924 and was originally named the Applied Science Building. It was built in conjunction with eight other buildings—the old forestry, agriculture, arts and administration buildings, the electrical and mechanical laboratories, the auditorium, and the mining, metallurgy and hydraulics building—all of which were built as semi-permanent buildings, and the total cost for all nine buildings was $500,000 (Geography Building). The function of the building was to house the academic needs of Geology, Civil Engineering, Zoology, Forestry and Botany, and was originally composed of 13 laboratories, 17 offices, 13 research and prep rooms, 12 lecture rooms, eight storage rooms, five lavatories and three locker rooms, as well as a library, museum and common room. The following table outlines the major building characteristics of the original Geography Building.

Table 1. Building Characteristics of the Geography Building

Building System	Specific Characteristics of Geography
Structure	Wood posts, girders and beams throughout
Floors	Foundation: Concrete Slab on grade; Ground and First Floors: Wood joists, Concrete suspended slab
Exterior Walls	Foundation: Cast-in-place walls; Ground and First Floors: Wood stud walls with stucco, cedar shiplap, laths on both sides, and plaster
Interior Walls	Foundation: Cast-in-place walls; Ground and First Floors: Lath and plaster on both sides of wood stud walls with plywood sheathing on hallway and lecture room walls
Windows	All windows fixed with wood frame and no glazing
Roof	Wood joist roof overlain by 2"x4" stud walls with cedar shiplap, roofing asphalt, and a 6mil polyethylene vapour barrier

Since its original construction, the Geography Building has undergone many renovations for a total of six phases of alterations. Some major alterations included wall, ceiling and room changes, additional fire exit stairwells, and the installation of two firewalls through the cross section of the building. The firewalls in particular required the two main stairwells to be demolished, as well as the walls on the ground and first floors between the front and rear entrances to be torn out (see Figure 1 below).

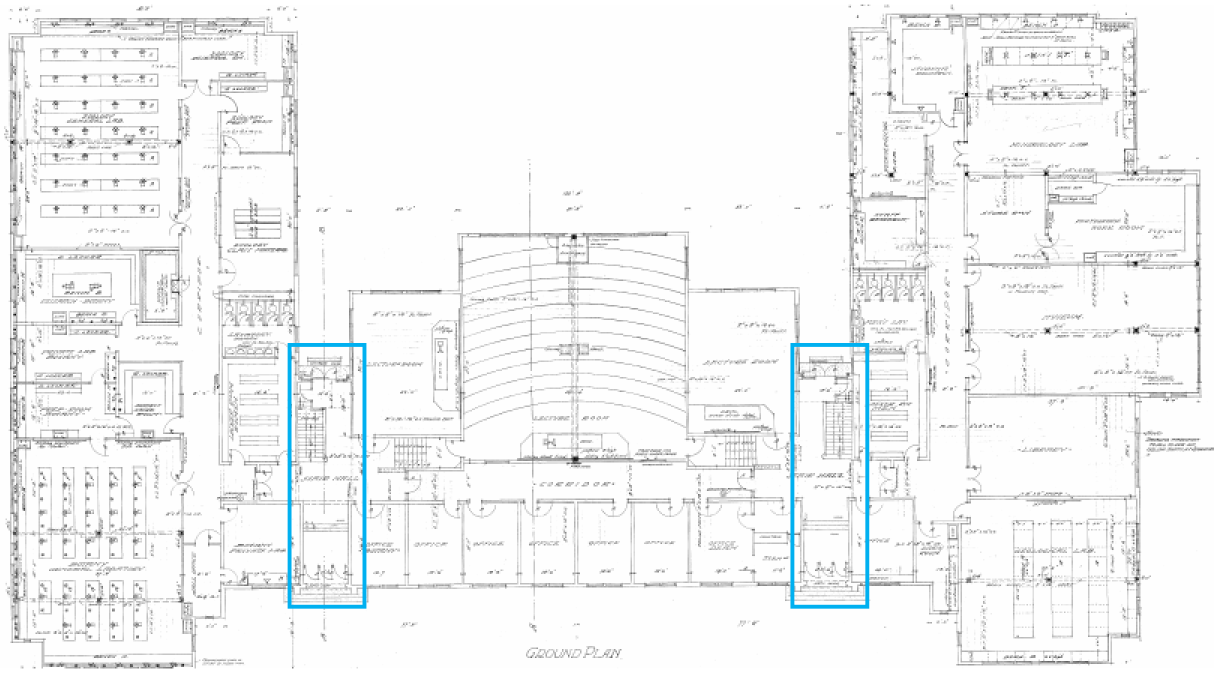

Figure 1. Ground plan highlighting the sections of building torn down for firewall installation

Overall, the building’s floors and exterior walls remain intact, but many of the interior walls have been altered to accommodate floor plan changes and new building requirements. This model, however, will represent the Geography Building as it was built in 1924, as if it were built today.

1 Goal and Scope

The initial stage of a life cycle analysis study is to clearly define the goal and scope. Conclusions and recommendations can then be made in accordance with the goal and scope, which affects the detail and time frame of the LCA. Using the ISO 14044 definitions and requirements as seen in section 4.2.2 and 4.2.3 (Canadian Standards Association, 2006), the following goal and scope was defined.

1.1 Goal of Study

This LCA of the Geography Building at the University of British Columbia was carried out as an exploratory study to determine the environmental impact of its design. This LCA of the Geography Building is also part of a series of twelve others being carried out simultaneously on respective buildings at UBC with the same goal and scope.

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the Geography Building. An exemplary application of these references is in the assessment of potential future performance upgrades to the structure and envelope of the Geography Building. When this study is considered in conjunction with the twelve other UBC building LCA studies, further applications include the possibility of carrying out environmental performance comparisons across UBC buildings over time and between different materials, structural types and building functions. Furthermore, as demonstrated through these potential applications, this Geography 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 audiences 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.

1.2 Scope of Study

The product system being studied in this LCA are the structure, envelope and operational energy usage associated with space conditioning of the Geography 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 Geography Building, as well as associated transportation effects throughout the manufacturing and construction stages.

1.2.1 Tools, Methodology and Data

Two main software tools are to be utilized to complete this LCA study; On Center's On-Screen 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, On-Screen Takeoff version 3.6.2.25 is used, which is a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. Using imported digital plans, the program simplifies the calculation and measurement of the takeoff process, while reducing the error associated with these two activities. The measurements generated are formatted into the inputs required for the IE building LCA software to complete the takeoff process. These formatted inputs as well as their associated assumptions can be viewed in Appendices A and B, respectively.

Using the formatted takeoff data, version 4.0.51 of the IE software, the only available software capable of meeting the requirements of this study, is used to generate a whole building LCA model for the Geography 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 and transportation of materials and their installation in to the initial structure and envelope assemblies. As this study is a cradle-to-gate assessment, the expected service life of the Geography 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 Geography Building, all of the available TRACI impact assessment categories available in the IE are included in this study, and are listed as;

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

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 Geography 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 calculates the energy payback period of investing in a better performing envelope.

The primary sources of data for this LCA are the original architectural drawings from when the Geography Building was initially constructed in 1924. Additional structural drawings from 2004 were also used to determine the live loading on the building. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as the associated envelope and openings (i.e. doors and windows) within each of these assemblies. The decision to omit other building components, such as flooring, electrical aspects, HVAC system, finishing and detailing, etc., are associated with the limitations of available data and the IE software, as well as to minimize the uncertainty of the model. In the analysis of these assemblies, some of the drawings lack sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in the IE software. Furthermore, there are inherent assumptions made by the IE software in order to generate the BoM and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further as they energy in the Building Model section and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Appendix B.

2 Building Model

In order to model the Geography Building for the purposes of completing this LCA study, On-Screen Takeoff and the IE Software were utilized. The initial materials quantity takeoffs were completed by measuring quantities available on the architectural drawings using On-Screen Takeoff. These materials were then inputted into the IE software and modeled, producing the subsequent the Bill of Materials, Summary Measures (impact assessment results) and Absolute Values (life cycle inventory results). The following sections discuss the methodology used with the On-Screen Takeoff and IE software, including assumptions and challenges associated with each of the programs.

2.1 Takeoffs

The On Center On-Screen Takeoff software provided a simplified method of producing material quantity takeoffs, while improving accuracy and modeling time. This was done by using linear, area and count conditions to measure materials available on the imported architectural drawings. When modeled in On-Screen Takeoff, the material quantities were separated by floor level—foundation, ground and first floor—and by material type— footings, exterior walls, interior walls, windows, doors, roof, floors, beams, girders, posts, stairs, and additional material. These were then organized into the following assemblies in the Impact Estimator Input Tables (Appendix A) to be modeled using the IE software: foundation, custom wall, mixed columns and beams, roof, floors, and extra basic material. A complementary Impact Estimator Input Assumptions Document can also be seen in Appendix B to further explain the assumptions necessary to model the building assemblies.

2.1.1 Foundation

For the foundation assembly, concrete footings were calculated using all three measurement conditions, and were assumed to be composed of concrete with 4000psi strength, #4 rebar reinforcement and average fly ash content. Column footings on the foundation were measured using the count condition with the width and length provided from drawing 401-06-016, and the thickness provided from drawing 401-06-17. They were then labeled based on the dimensions—e.g. 4’x4’ Concrete Footing. The strip footing below the exterior concrete wall was modeled using the width provided from drawing 401-06-016 and the linear condition used to measure the Foundation Exterior Wall with Footings, and was labeled accordingly. The concrete stairs on the ground level—which were modeled as footings and labeled as Ground Entrance Stairs—were measured using the area condition, with the average thickness estimated from the cross section as shown in drawing 401-06-020. Finally, Foundation Concrete Floor was modeled as a slab on grade using the area condition, with a thickness measurement of 4". The concrete for the slab was assumed to have strength of 4000psi and average fly ash content.

2.1.2 Walls

The walls on the foundation, ground and first floor levels were modeled using linear conditions labeled based on their thickness, material, floor level and if they were interior or exterior walls (e.g. Foundation 6" Interior Concrete Wall, Ground 2"x4" Stud Interior Wall, etc). The foundation concrete walls were assumed to have a height of 3.5ft, based on an average of measurements from drawings 401-06-019 and 401-06-020, as well as concrete with 4000psi strength, #5 rebar reinforcement and average fly ash content. In addition, the exterior walls on the ground and first floors appeared to have no insulation installed when the building was initially constructed, and were therefore assumed to have no insulation. Hallway walls were also assumed to have plywood sheathing, based on drawing 401-06-030, a drawing from a building renovation in 1963. The doors and windows within the ground and first floor walls were modeled using count conditions. All doors, except for the steel vestibule which was assumed to be a 32"x7' steel interior door, were assumed to be 32"x7' solid wood doors. The windows were assumed to be fixed windows with standard glazing, and were modeled as wood frames based on site inspections. Finally, all wood stud walls with lath and plaster required ½" of regular gypsum to be used as a surrogate material for the plaster, with the laths modeled as extra basic material based on 4'x2"x¼" dimensions and ¼" spacing (Lath and Plaster, 2008).

2.1.3 Columns and Beams

The beams and girders were modeled in On-Screen Takeoff using linear conditions combined with cross section dimensions given by the drawing 401-06-016, 401-06-017 and 401-06-18. The posts were also modeled using dimensions from the above drawings and drawing 401-06-020 for post heights, as well at count conditions. All beams, girders and posts were labeled based on dimensions, floor level and material, and were modeled using extra basic materials to simplify calculations.

2.1.4 Roof

The roof of the building was made up of two wood joist sections, as seen in Figure 2 below. The lower portion was modeled as a wood joist roof with a span of 10ft due to IE limitations, while the upper portion was modeled as 4 separate wall sections with 2"x4" wood studs. In addition, for sloped sections of the "wall sections," the section was assumed to be flat. From the roof detail, cedar shiplap was added to the envelope, as well as roof asphalt based on site inspections. In addition, it was assumed there was a 6mil polyethylene layer to meet the vapour barrier requirements of a roof.

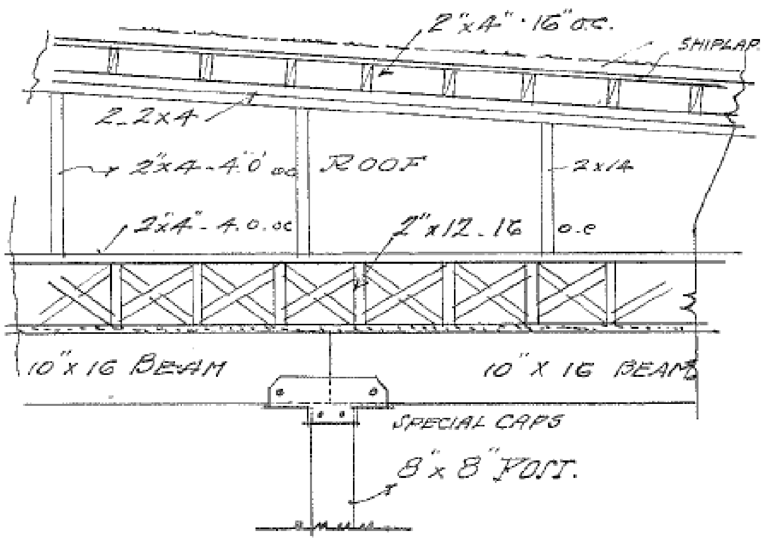

Figure 2. Roof detail for the Geography Building

2.1.5 Floors

The floors in the Geography building were modeled using the area condition, and were labeled based on their material, floor level and location (e.g. Ground Concrete Floor, Ground Sloped Lecture Room). For all the floors, an assumed live load of 45psf was also used based on drawing 401-07-001, a list of specifications from a 2004 renovation. The concrete floor had an assumed 4000psi strength and average fly ash content. An assumed span of 16ft was also used to fit within the 11.8ft - 32.0ft span limitation of the IE software. The wood joist floors were assumed to have ½” thick plywood decking based on knowledge of the decking being wood. In addition, the spans were assumed to be 10ft to fit within the 0.98ft - 15.0ft span limitation of the IE software. Finally, the sloped section of the lecture room was modeled to have a slope based on the dimensions of the risers and treads of the steps, as seen in drawing 401-06-019. A sloped wood joist floor was modeled, and the addition material used for the steps was added as extra basic material. This volume of material was calculated based on the number of steps, and the dimensions of the risers and treads. In addition, it was assumed that the steps had a width of 50ft, based on a drawing measurement, and the wood steps were ½” thick.

2.1.6 Extra Material

The remaining materials, including the First Floor Truss and the wood stairwells, were modeled using extra basic material. The wood, steel rod and steel sheets of the truss were modeled based on the drawing 401-06-018. The stairwells were modeled similar to that of the truss, with volumes calculated basic on the number of steps, the dimensions of the risers and treads, and an assumed thickness of ½”. 2”x8” stringer boards were also considered in the quantity takeoff of the steps.

Overall, the drawings were high quality, allowing the takeoffs to be performed with ease. There was lack of information concerning concrete properties, foundation assembly heights and wall cross-sections, and assumptions were made based on research. In addition, some material quantities required assemblies to be factored due to limitations with the IE software. Further detailed information and calculations on all assumptions made can be found in the Impact Estimator Input Assumptions Document (Appendix B).

2.2 Bill of Materials

The BoM is a list generated from the material quantity takeoffs. As seen in Table 2, the five largest values by units of area were ½” regular gypsum board, softwood plywood, 6mil polyethylene, cedar wood shiplap siding, and stucco, and largest value by weight was joint compound.

Table 2. Bill of Materials for the Geography Building

Material	Quantity	Unit
1/2" Regular Gypsum Board	109073.9334	sf
6 mil Polyethylene	27342.16232	sf
Aluminium	1.80844	Tons
Batt. Fiberglass	617.36408	sf (1")
Cedar Wood Shiplap Siding	48016.5127	sf
Cold Rolled Sheet	1.60263	Tons
Concrete 30 MPa (flyash av)	282.91234	yd3
EPDM membrane	2356.71954	pounds
Galvanized Sheet	0.00327	Tons
Glazing Panel	0.04218	Tons
Joint Compound	9.17297	Tons
Large Dimension Softwood Lumber, Green	26.99098	Mbfm
Large Dimension Softwood Lumber, kiln-dried	77.57556	Mbfm
Nails	2.8332	Tons
Paper Tape	0.10631	Tons
Rebar, Rod, Light Sections	5.01469	Tons
Roofing Asphalt	5279.14524	pounds
Small Dimension Softwood Lumber, kiln-dried	104.46044	Mbfm
Softwood Plywood	91.85782	msf (3/8inch)
Solvent Based Alkyd Paint	0.07789	US gallons
Standard Glazing	7326.85389	sf
Stucco over porous surface	21950.5196	sf
Water Based Latex Paint	246.78011	US gallons
Welded Wire Mesh / Ladder Wire	0.042	Tons
Wood Frame	34.79803	yd3

The amount of ½” regular gypsum board and joint compound is a result of the lath and plaster present on the inside of all exterior walls, as well as both sides of all interior walls—this includes assemblies 2.2.1 to 2.2.11 as seen in Appendix A. From the assumptions, it is known that the gypsum board was used as a surrogate for the plaster walls. The quantity of joint compound is also associated with this replacement, because joint compound is used to seal the joints between sheets of gypsum board. This assumption used on such a widely used material can then greatly affect the environmental impacts that this building will have, because gypsum board and joint compound do not have the same properties as plaster. In addition, the type of gypsum board and thickness were assumed based on research. As a result, if the plaster would have been better modeled at 5/8” gypsum board then the total volume would have been underestimated by 20%. This assumption could be a potential source of uncertainty in the model’s results.

The softwood plywood was generated in the BoM from its presence in the Ground Floor Area, Ground Level Lecture Room and the First Floor Floor Area, as well as the Ground 2"x4" Stud Hallway Wall and Lecture Room Wall, and the First Floor 2"x4" Stud Hallway Wall. The wood on the floors was assumed to be plywood due to lack in information in the drawings, however, they may have been solid wood. This could have resulted in an underestimation of wood volume, as well as an overestimation of wood adhesives. In addition, the plywood sheathing in the hallway walls was assumed based on drawing 401-06-030, a drawing from a 1963 renovation that may have not been cohesive with the original state of the building. Had there originally been no plywood sheathing, the modeled BoM would show an overestimation of the product. The plywood was also assumed to only be present within the hallways wall rather that all of the walls. If the sheathing was actually present in all of the walls, the quantity of plywood would have been an underestimation.

Polyethylene was another material with a high quantity for the building; however, the use of this product was based solely on the need to meet a roof requirement for the Roof Area. As a result, if this is not the actual material, the impacts that the building has could be altered. The actual vapour barrier may have also had a different thickness and the assumption could have resulted in an over- or underestimation, depending on whether the original thickness was thinner or thicker, respectively. Finally, had this material not been present at all, as depicted in the architectural drawings, a 100% overestimation would have been quantified in the bill of materials.

The cedar wood shiplap siding, which resulted from the wall cross sections of the Ground Exterior Wall and First Floor Exterior Wall, as well as the Roof Area, was input into the IE software by square foot, and the thickness was determined based on the IE software information. If the thickness used was ¾", which is the same shiplap thickness given in drawing 401-06-028 from a 1962 renovation, then the error in volume approximations of this material for the exterior walls would be minimal; however, differences in this thickness could result in quantity over- or underestimations. Finally, the shiplap modeled for the Roof Area was on the upper portion of the roof, which was sloped (see Figure 2 above). This section of roof, however, was assumed to be flat causing an underestimation of the cedar wood shiplap siding area.

Stucco was present throughout the outside of the building for the ground and first floors on the Ground Exterior Wall and the First Floor Exterior Wall. Similar to the cedar wood shiplap siding, whether or not the material takeoff resulted in an over- or underestimation of stucco depends on the thickness used by the IE software.

As one can see, all of the largest material quantities were subject to assumptions that could affect their amount and/or impacts to some degree. Some materials, such as the softwood plywood where the material quantity was assumed, could have resulted in quantity differences. Other material, such as the gypsum board and joint compound used as a surrogate for plaster, could have resulted in impact differences based on different material compositions. These considerations must therefore be taken into account when analyzing the results of the Geography Building model.

3 Summary Measures

The summary measures that were considered for the purposes of this report include primary energy consumption, weighted resource use, global warming potential, acidification potential, human health (HH) respiratory effects potential, eutrophication potential, ozone depletion potential and smog potential. These impacts are calculated by the impact assessment methodology, TRACI, given characterization factors for material emissions—e.g. 1kg CH_4 release = 23kg CO_2 release. In addition, they were considered over the manufacturing and construction life cycle stage of the Geography Building.

Sensitivity analysis was also performed for each of the summary measures to determine their sensitivity to 10% increases in aluminum, concrete, asphalt, plywood and stucco. This can process can be helpful during the design or renovation stages of buildings to compare environmental tradeoffs between interchangeable products, such as different insulation and wall framing materials. It can also put emphasis on the need to waste as little material as possible, because even a 10% increase in a single material can have sizeable impacts on the overall building profile.

In the following sections, the different impact categories are defined and their sensitivities are presented and discussed. Overall impacts and sensitivities are also presented, and the Geography Building is compared to an average of the academic buildings modeled. Finally, uncertainties inherent in these impact calculations are discussed.

3.1 Primary Energy Consumption

Primary energy consumption, measured in MJ, is the total energy used during manufacturing and construction stages. This includes the amount of energy allocated to all of the components of a material—such as aggregates, cement, cementitious materials and water for concrete—for extraction, processing, transportation and installation. The increase in primary energy consumption can impact other summary measures, such as global warming potential, depending on the energy source that is being used.

As seen in Figure 3, all of the materials considered had a visible effect on the primary energy consumption, ranging from an additional 0.026% to 1.18%. This is because all of the materials require being manufactured and constructed. The 10% increase in concrete (originally 282.81yd^3) had the highest effect on the primary energy, with the increase in plywood (originally 91.86msf) having the second highest effect. The increase in aluminum (originally 1.81tons) and asphalt (originally 2.64tons) both had approximately 0.14% increases in energy per ton, which was relatively high considering their low quantity. Finally, stucco caused a minor increase of 0.026%.

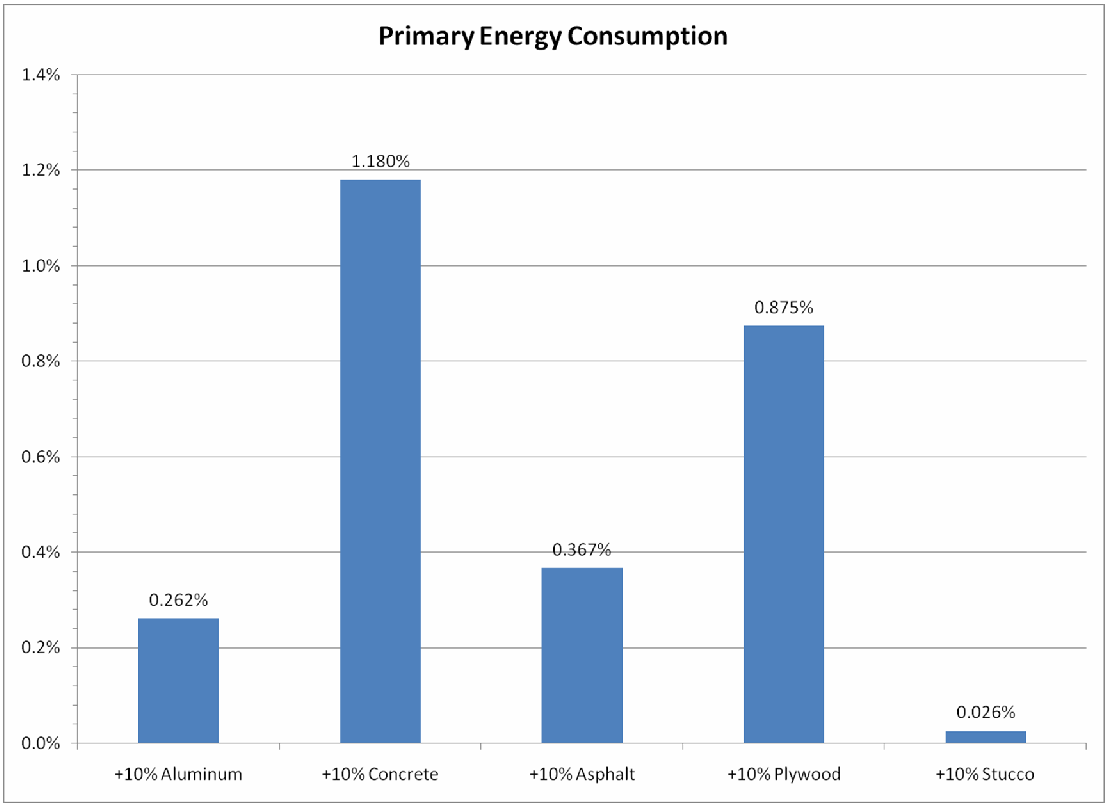

Figure 3. Sensitivity of primary energy consumption to changes in material quantities

3.2 Weighted Resource Use

Weighted resource use, measured in kg, accounts for the all of the resource requirements for all of the components of a material. This includes the sum of all of the land, fossil fuel and water use required to manufacture and construct that material.

Figure 4 below shows the sensitivity of weighted resource use to changes in aluminum, concrete, asphalt, plywood and stucco. From the figure, it is clear from that the increase in concrete had the most significant impact on weighted resource use, with plywood having the second most significant impact. Aluminum and asphalt also had minor effects on the summary measure, while the increase in stucco had a negligible effect.

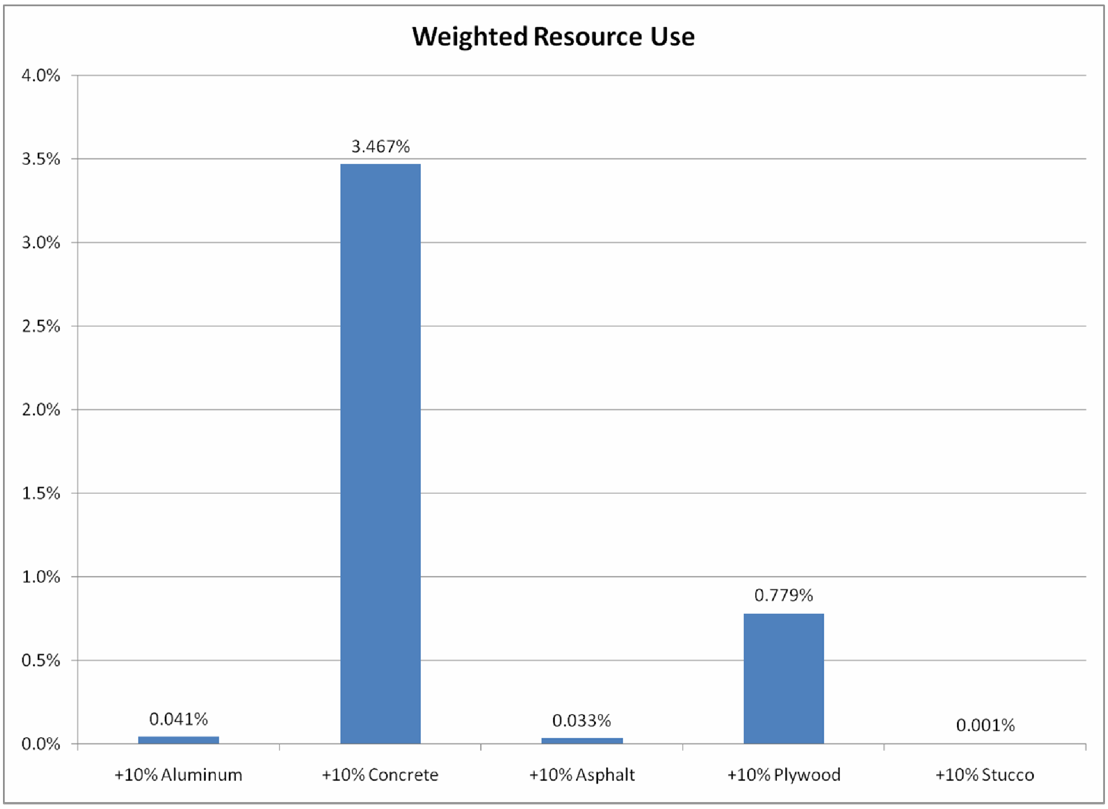

Figure 4. Sensitivity of weighted resource to changes in material quantities

3.3 Global Warming Potential

Global warming potential, measured in kg CO_2 equivalent, is the potential for the earth's climate to change based on the buildup of chemicals, and subsequent heat entrapment. The chemicals that affect this summary measure include greenhouse gases, and the total effect is based on their "radiative forcing and lifetime" (Bare, Norris, Pennington, & McKone, 2003).

Figure 5 shows the sensitivity of the building's global warming potential to the five materials observed. As seen above, the concrete had the highest effect on the global warming potential due to the high CO_2 emissions that are caused during the calcinations and carbonation phases of cement production. Aluminum, asphalt and plywood had approximately equal increases in global warming potential per quantity, but had much lower effects than concrete. Stucco, however, had negligible effects on the summary measure.

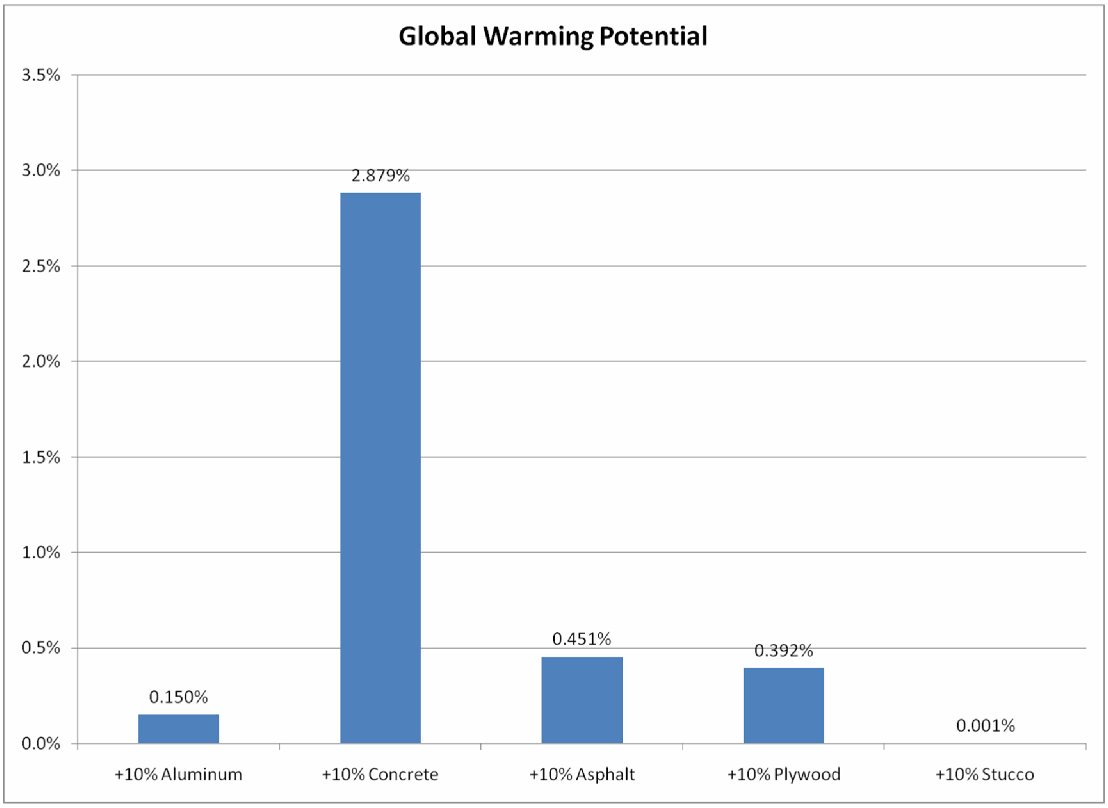

Figure 5. Sensitivity of global warming potential to changes in material quantities

3.4 Acidification Potential

Acidification, measured in moles of H+ equivalent, is the potential for an increase of acidity of water and oil systems to occur. This can occur through both wet and dry depositions, and is caused by SO_2 and NO_x emissions (Bare, Norris, Pennington, & McKone, 2003).

In Figure 6, it can be seen that the acidification potential of the Geography Building was most sensitive to an increase in concrete, while aluminum, asphalt and plywood had much lower effects than concrete. Once again, the 10% increase in stucco had negligible effects on the acidification potential.

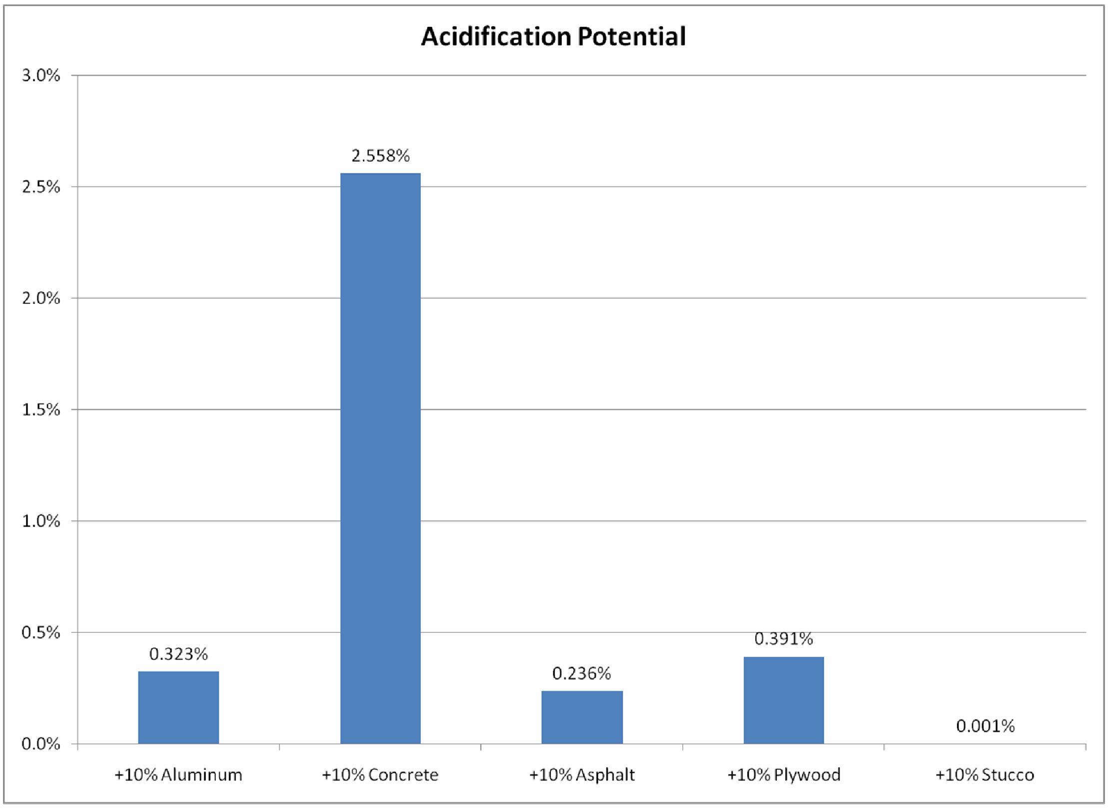

Figure 6. Sensitivity of acidification potential to changes in material quantities

3.4.1 Human Health Respiratory Effects Potential

HH respiratory effects potential is affected by the "total suspended particulates, particulate material (PM) less than 10μm in diameter (PM_{10}), PM less than 2.5μm in diameter ($PM_{2.5}$), and by emissions of SO2 and NOx" (Bare, Norris, Pennington, & McKone, 2003), and is measured in kg $PM_{2.5}$ equivalent. These particles can have toxic effects on human health, including "chronic and acute respiratory symptoms, as well as mortality" (Bare, Norris, Pennington, & McKone, 2003).

In Figure 7 below, the sensitivity of HH respiratory effects potential to changes in the five observed materials is shown. The 10% quantity increase of concrete had the greatest effect on HH respiratory effect potential, with aluminum and plywood having the second and third higher effects, respectively. Finally, asphalt had very minimal effects and the increase in stucco had negligible effects.

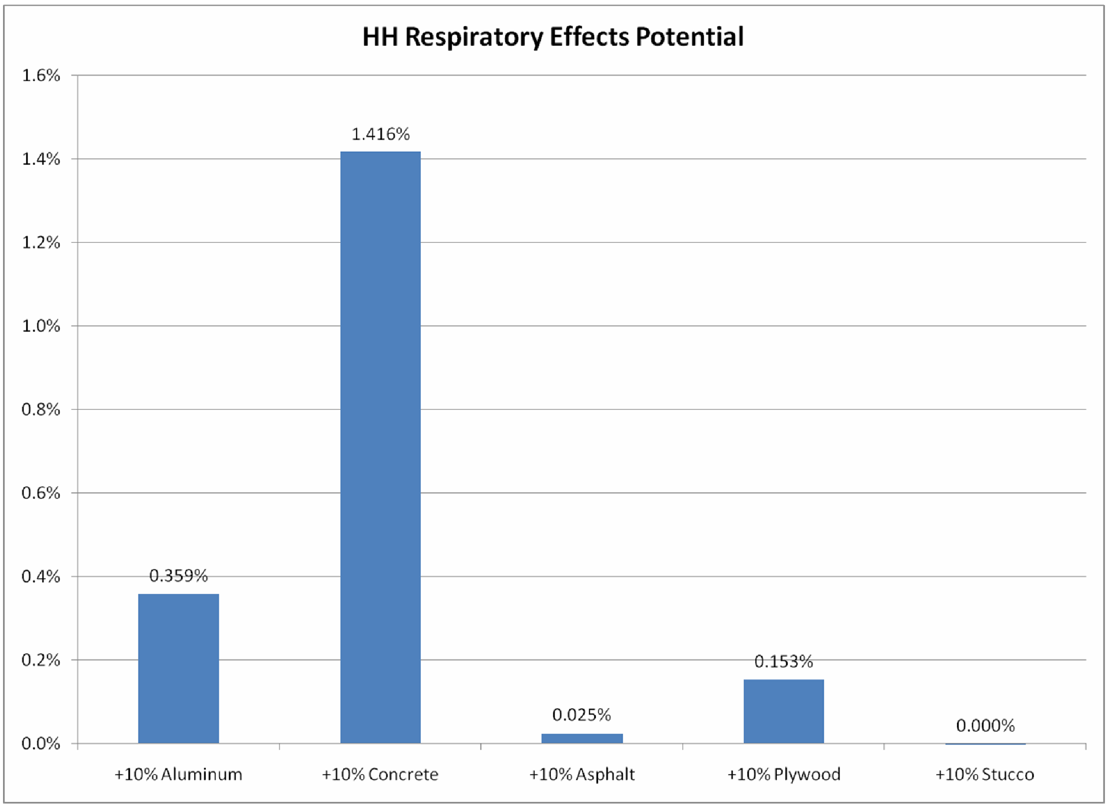

Figure 7. Sensitivity of human health respiratory effects potential to changes in material quantities

3.5 Eutrophication Potential

Eutrophication potential, which is measured in kg N equivalent, is the potential for materials and their emissions to fertilize surface waters with previously scarce nutrients. This can then cause an expansion of aquatic photosynthetic plant species, leading to possible odours, decrease in marine habitat and production of chemicals that could be a health hazard.

In Figure 8, it can be seen that the eutrophication potential was highly sensitive to concrete, with an effect of 0.175%, and asphalt, with an effect of 0.112%. Plywood also had a significant impact of 0.102%, and aluminum had an effect of 0.033%. Finally, stucco had a negligible effect of the eutrophication potential.

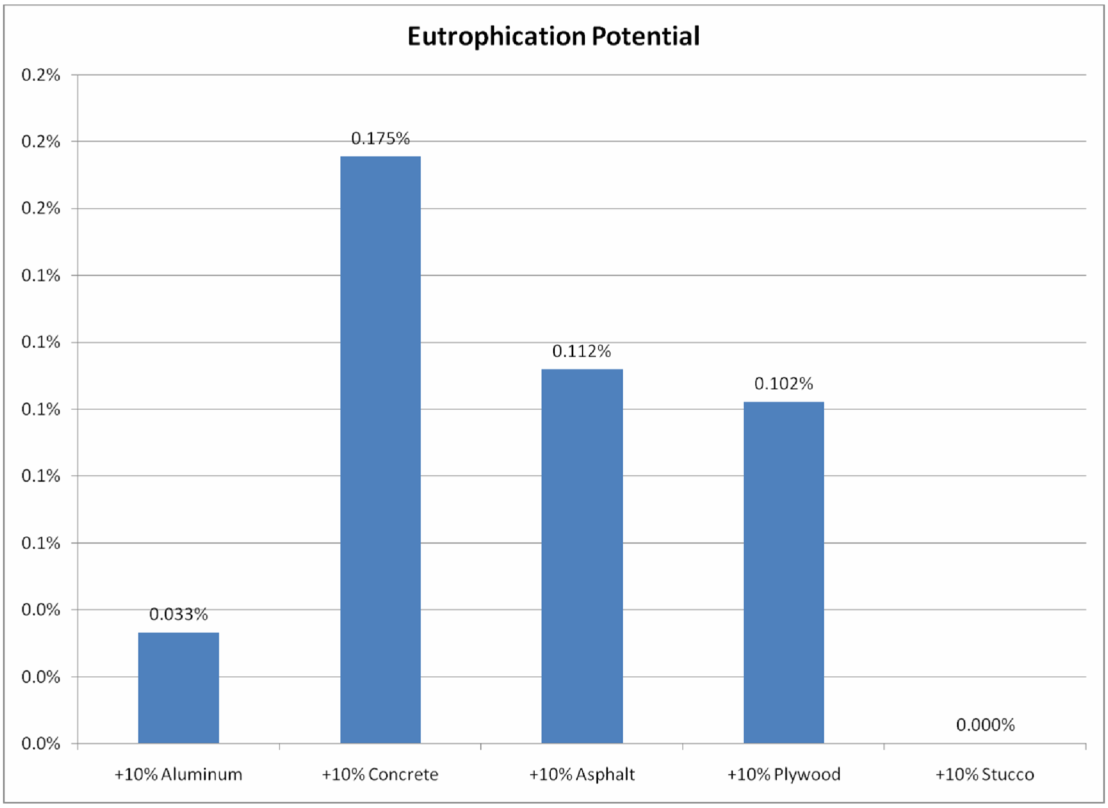

Figure 8. Sensitivity of eutrophication potential to changes in material quantities

3.6 Ozone depletion potential

Ozone depletion potential, measured in kg CFC-11 equivalent, is the potential for reduction of the protective ozone due to accelerated destructive chemical reactions caused by chlorofluorocarbons (CFCs), halons and other chemicals. This reduction can cause lower level ozone level, which can cause increased UVB levels and harmful effects on marine life, crops and human health—including cancer (Bare, Norris, Pennington, & McKone, 2003).

As seen in Figure 9, the plywood had the largest effect on ozone depletion of 2.510%, with concrete having the second highest effect of 0.213%. In addition, aluminum, asphalt and stucco had negligible effect on the summary measure.

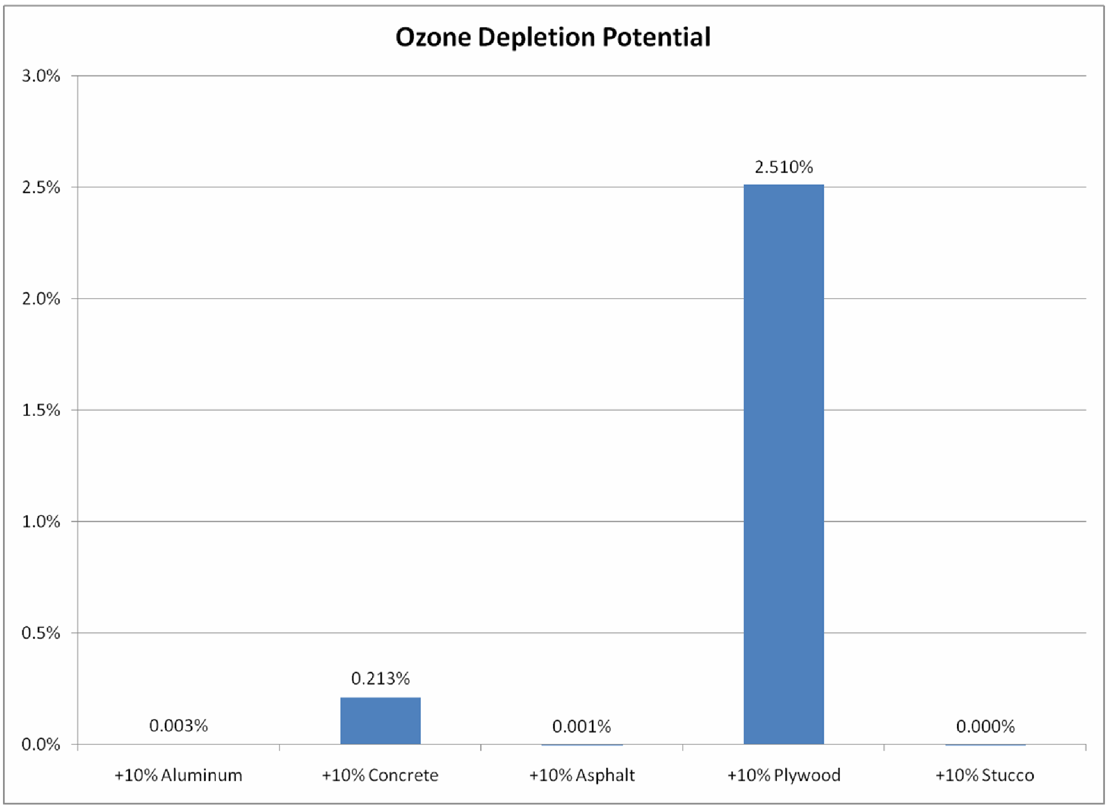

Figure 9. Sensitivity of ozone depletion potential to changes in material quantities

3.7 Smog potential

Smog potential, which is measured in kg NO_x equivalent, is the potential for material emissions to cause smog. This can cause harmful effect on human health, including asthma and mortality, and can be deleterious to plant life.

As seen in Figure 10, smog potential was most sensitive to the increase in concrete, which caused an increase of 3.908%. Aluminum had the second greatest effect with 0.616%, and then asphalt had the third greatest effect with 0.371%. Finally, plywood had a minimal effect on smog potential with a change of 0.143% in the summary measure, and stucco is negligible.

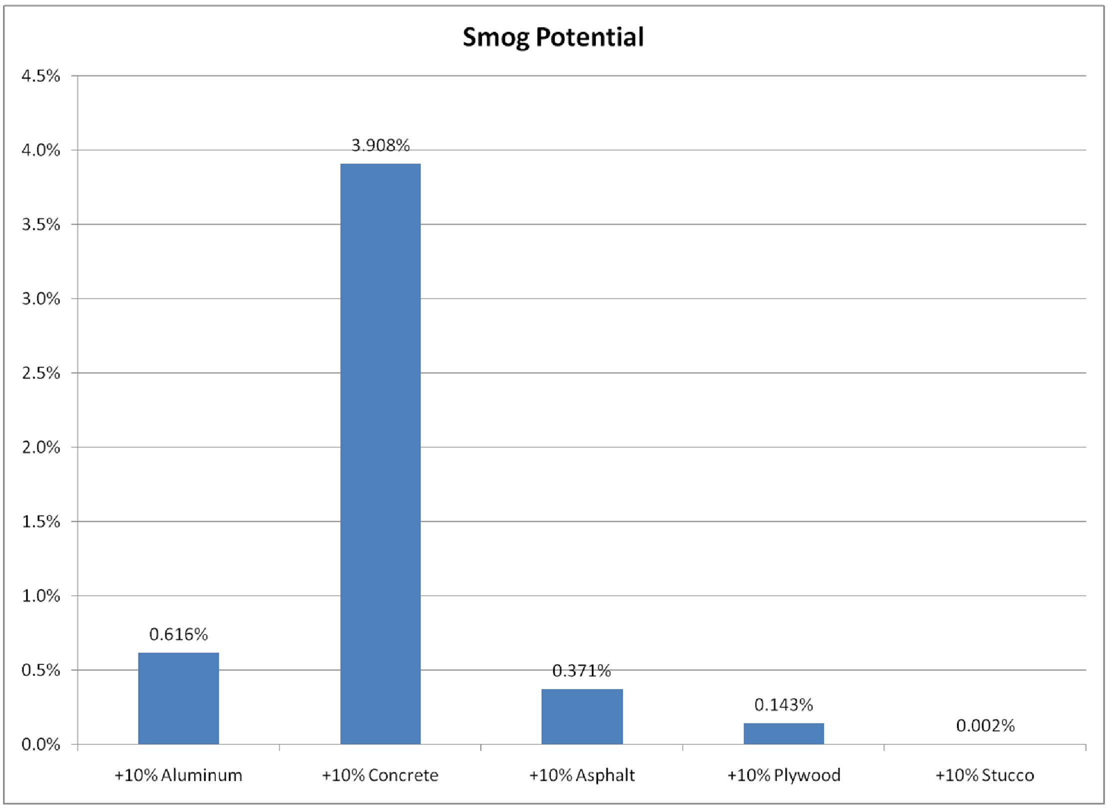

Figure 10. Sensitivity of smog potential to changes in material quantities

3.8 Overall Impacts

The overall impacts of the manufacturing and construction life cycle stages of the Geography are present in Table 3 below.

Table 3. Manufacturing and construction impacts of the original building

Impact Category	Manufacturing Total	Construction Total	Total Effects (Man. + Constr.) Overall	Per Sq. Ft
Primary Energy Consumption	3254101.396	220370.0547	3,474,471.45	67.03
Weighted Resource Use	1750369.705	6002.468045	1,756,372.17	33.89
Global Warming Potential	207751.8251	5182.253076	212,934.08	4.11
Acidification Potential	78961.93478	2730.497823	81,692.43	1.58
HH Respiratory Effects Potential	1013.510967	2.761592338	1,016.27	0.02
Eutrophication Potential	1.841440174	0.00143683	1.84	0.00
Ozone Depletion Potential	0.006051019	1.37544E-08	0.01	0.00
Smog Potential	766.071318	47.74132725	813.81	0.02

To compare the Geography Building to other academic buildings on the UBC Vancouver campus, these impacts were then converted to a per square foot basis. This was done for all seven buildings considered—Geography, Henning's, Buchanan, H. R. MacMillan, CEME, FSC and AERL—and then average impacts were found. Below, in Figure 11, the Geography Building was compared to the average academic building.

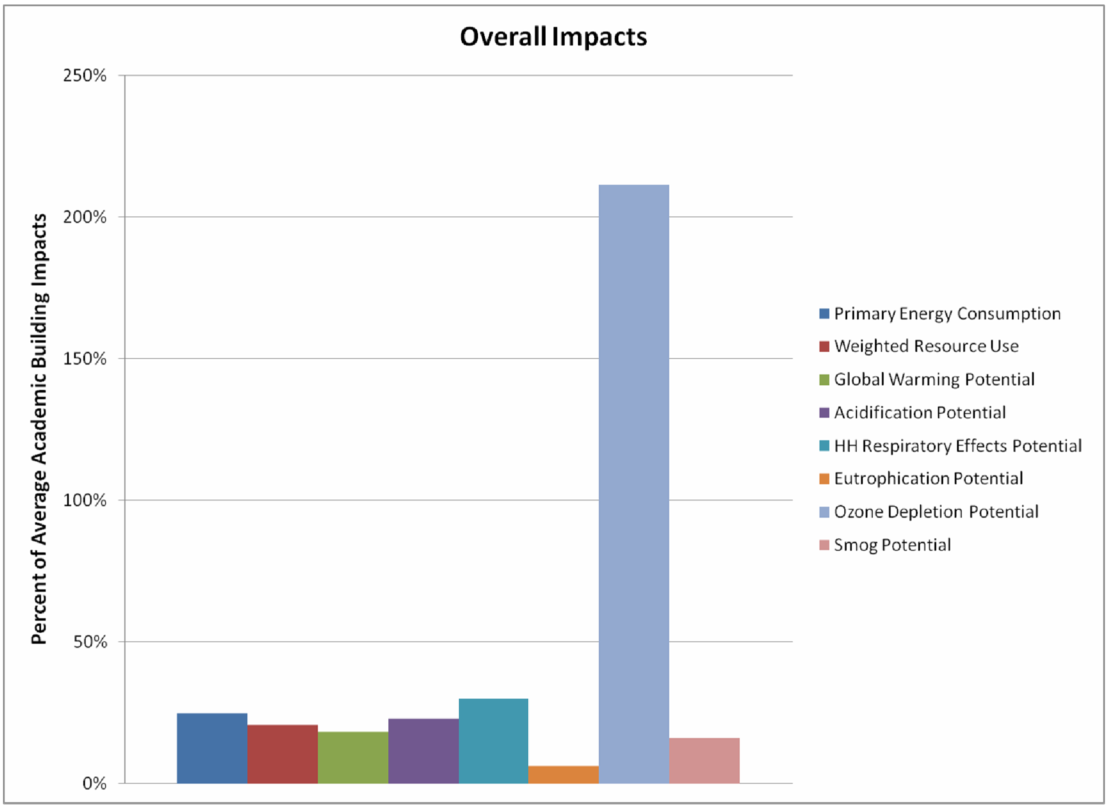

Figure 11. Overall impacts of the Geography Building compared to average academic buildings

As seen in Figure 11, the Geography Building's primary energy consumption, weighted resource use, global warming potential, acidification potential, HH respiratory effects potential, and smog potential were approximately 25% of the average UBC academic building. This seems to be associated with the fact that the Geography Building is mainly constructed of wood, compared to the concrete and steel structures that are prevailing in the other buildings. In addition, the eutrophication potential was approximately 6% that of the average academic building. The ozone depletion potential, however, was 211% that of the average academic building. This is likely due to the large use of plywood in the Geography Building, to which the ozone depletion potential was relatively sensitive to, as seen in Figure 9.

The sensitivity of all of the summary measures to material quantity changes is also presented in Figure 12.

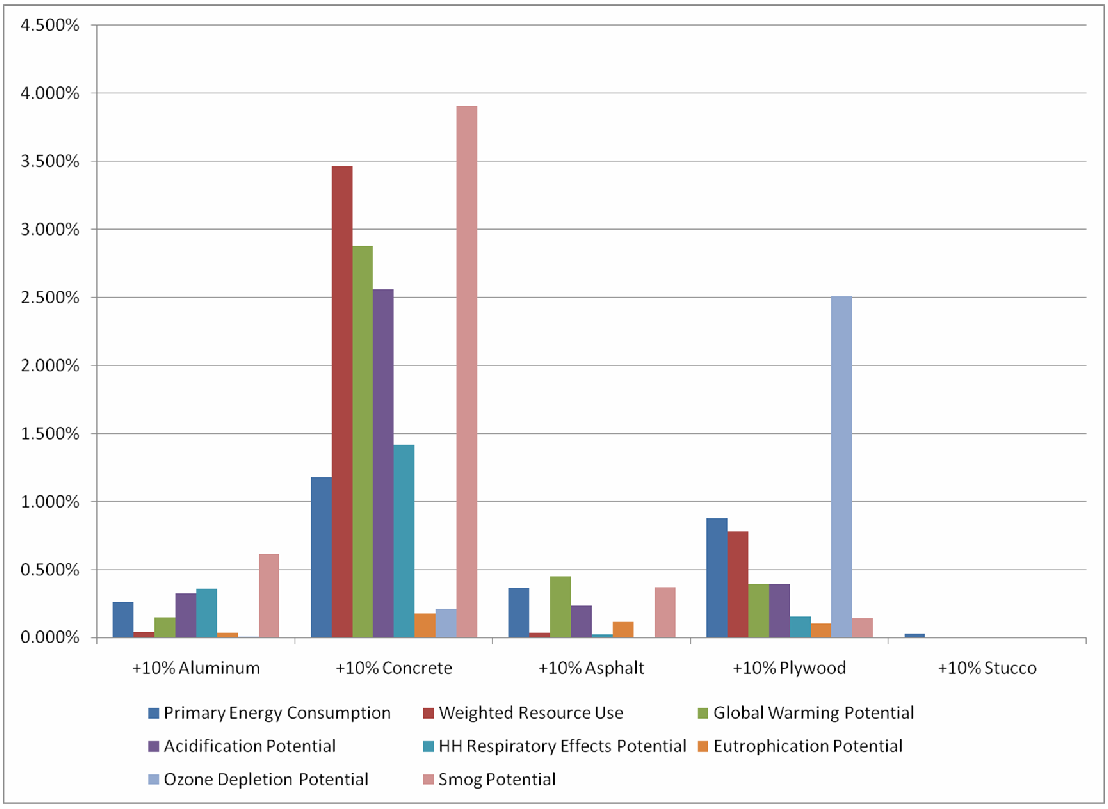

Figure 12. Sensitivity of all summary measures to the change in material quantities

It can be seen from the figure that the increase in aluminum caused the most effect on smog potential. The next highest summary measures impacted by aluminum were primary energy consumption, acidification potential and HH respiratory effects potential, which were all approximately equal. Finally, the global warming potential was slightly affected by aluminum, and eutrophication potential and weighted resource use were minimally affected.

The summary measures that were more affected by concrete—in decreasing order—were smog potential, weighted resource use, global warming potential and acidification potential.

Primary energy consumption and HH respiratory effects potential were more affected summary measures, with approximately equal effects. Finally, eutrophication potential and ozone depletion potential were relatively minimal.

Global warming potential, smog potential and primary energy consumption—in decreasing order—were most affect by the change in asphalt. Acidification potential and eutrophication potential were the following most affect summary measures, with weighted resource use, HH respiratory effects potential and ozone depletion potential relatively minimal.

The summary measure that plywood most affected was ozone depletion potential. The next summary measures that were most affect were primary energy consumption and weighted resource use, then global warming potential and acidification potential. Finally, the increase in plywood had relatively minimal effects on HH respiratory effects potential, eutrophication potential and smog potential.

Finally, the 10% increase in stucco had very minimal effects on all of the summary measures. The only summary measure that had a visible effect from the increase in stucco was primary energy consumption.

3.9 Uncertainties in Impact Assessment

Due to the complex nature of summary measures, assumptions and uncertainties arise during the impact assessment process. These uncertainties can be due to the characterization of emissions, the location of the emissions, and the characteristics of the environment these emissions are subjected to. In addition, how the model was performed and over what scope can also affect the certainty of the impacts.

The impact assessment methodology used for this study was a non-regionalized version of TRACI. As a result, the assessment did not take into account differing environmental conditions for different areas. This could cause uncertainty in how the emissions are absorbed by chemical sinks, such as trees and water, and the potential of the emissions to travel and affect the environment on different geographic scales. In addition, it was not taken into account whether or not the pollutants are emitted within the building or outside of the building. This makes a difference on the environmental impacts because if the pollutants are emitted where there are lots of people, they are more likely to have a negative impact on human health.

Not all characteristics of emissions are taken into account when doing an impact assessment. The impact assessment software converts specified amounts masses of emissions into their equivalent environmental and human impacts. Although this data had been collected through many environmental and health studies, the impacts are still dependent on an infinite number of factors—such as time, temperature, environment sensitivity, etc.— compromising the accuracy of these impact equivalencies. In addition, there are a number of chemicals within the environment that can react together to produce other chemicals. This reaction could potentially create more or less hazardous chemicals. Overall, this lack of detail could result in over- or underestimation of environmental impacts.

The way that the emissions are converted to impacts can also cause uncertainty in the summary measures. TRACI, the impact assessment methodology used for this study, relates emissions to impacts through characterization factors. These factors, however, are linear and do not take into account the initial amount that the environment is able to absorb without effects, as well as the drop off of effects when there are so many emissions that further emissions do not cause any more harm. This could cause over- or underestimations of the impacts, depending on the relationship the each emission has with the environment.

Finally, the way in which the impact assessment methodology allocates impacts to different products along the line of production can affect the overall results. Co-products from the same unit process can be quantified by mass, volume, economic value, etc. Depending on which method of quantification is used, the impacts allocated to each co-product will differ.

4 Building Performance

The building performance of the current Geography Building was calculated based on the total areas and heat flow resistances (R-values) of the roof, windows and exterior walls, as well as the initial embodied energy of the building. This building performance was then compared to a theoretical improved Geography Building that met the Residential Environmental Assessment Program's (REAP's) insulation requirements. The following sections outline the method of calculating the R-values and subsequent energy performances, the materials to be replaced to increase building performance, and the energy payback period of such replacements.

4.1 Heat Flow Resistance

The R-values of the current and improved buildings' windows were determined from tables provided. The R-values for the exterior walls and roofs, however, needed to be calculated based on the components in the assemblies' cross-sections and the area that they covered (R-Value Table, 2008). For components that only covered the area of the assembly's studs, the R-value was input into the "R-Value Studs" column as seen in Table 4. For components that only covered the area of the cavities between the studs, the R-value was input into the "R-Value Cavity" column. For components that covered the whole assembly area, the R-value was input into both the "R-Value Studs" and "R-Value Studs" columns.

Table 4. Sample R-value calculation table

Component	R-Value Studs	R-Value Cavity	Assembly R-Value
Total Wall R-Values			
Wall U-Values			
Total Wall R-Value			

The total R-values for the stud and cavity sections were determined by summing all of the R-values within the column. The U-values were then calculated by taking the reciprocal of the R-values. Finally, the total R-value for the assembly was calculation by Equation 1, where the “%” variables are the percent area occupied by the studs and the cavities:

Equation 1:

$$Assembly\ R-Value = \frac{1}{Assembly\ U-value} = \frac{1}{(Ustuds*\% + Ucavity*\%)}$$

Once the R-values of each assembly was determined, the weighted average R-value for the whole building was calculated by taking the sum of the products of the R-values and areas for each assembly, and dividing the sum by the total area of all of the assemblies. The following sections outline how the R-value for each assembly was modeled.

4.1.1 Current Building

The Geography Building had single-pane windows with assumed standard glazing. From the R-Value Table provided on the Colorado Energy website (R-Value Table, 2008), it was determined that this had an R-value of 0.91.

The exterior wall cross section for the Geography Building included stucco, cedar shiplap siding, 2”x4” wood studs and plaster. Due to limitations, however, stucco could not be input into the R-value calculation, the cedar shiplap siding was assumed to be wood bevel siding, and the lath and plaster were assumed to be ½” drywall. Outside and inside air films were also added to the model. Finally, the studs were input as 3 ½” studs, and the total percent area of the studs was estimated to be 15%. These assumptions resulted in an exterior R-value of 3.36, as seen in Table 5.

Table 5. Exterior wall R-value calculation for the "current" building

Exterior Wall R-Value Calculation for "Current" Building			
Component	**R-Value Studs**	**R-Value Cavity**	**Assembly R-Value**
Wall - Outside Air Film	0.17	0.17	
Siding - Wood Bevel	0.8	0.8	
3 1/2" Stud	4.38		
Air space (within stud cavities)	0	1	
1/2" Drywall	0.45	0.45	
Inside Air Film	0.68	0.68	
Percent for 16" o.c. + Additional studs	15%	85%	
Total Wall R-Values	**6.48**	**3.1**	
Wall U-Values	**0.15**	**0.32**	
Total Wall R-Value			**3.36**

The roof cross section for the Geography Building included roofing asphalt, cedar shiplap siding, and two layers of 2”x4” wood studs with 26” of air space between them. Due to limitations, however, the cedar shiplap siding was assumed to be wood bevel siding and the roofing asphalt was assumed to be asphalt shingles. Outside and inside air films were also added to the model. Finally, the studs were input as 3 ½” studs, and the total percent area of the studs was estimated to be 5%. These assumptions resulted in an exterior R-value of 10.30, as seen in Table 6.

Table 6. Roof R-value calculation for the "current" building

Roof R-Value Calculation for "Current" Building			
Component	**R-Value Studs**	**R-Value Cavity**	**Assembly R-Value**
Wall - Outside Air Film	0.17	0.17	
Siding - Wood Bevel	0.8	0.8	
3 1/2" Stud	8.76	0	
Air space (between stud assemblies)	6	6	
Air space (within stud cavities)	0	2	
Asphalt Shingles	0.44	0.44	
Inside Air Film	0.68	0.68	
Percent for 16" o.c. + Additional studs	5.0%	95.0%	
Total Wall Component R-Values	**16.85**	**10.09**	
Wall Component U-Values	**0.06**	**0.10**	
Total Wall Assembly R-Value			**10.30**

4.1.2 Improved Building

To improve the window insulation and meet the REAP window insulation standard of at least R-2.85, low E tin argon filled glazing was used, which have an R-value of 3.45

To improve the exterior walls’ energy performance and meet the REAP exterior wall insulation standard of at least R-18, 3.5” of polyisocyanurate insulation was added to the assembly. Because the wall cross section did not currently detail any insulation in the current building, the rest of the assembly was kept the same. The resulting exterior wall R-value was 18.42 as seen in Table 7.

Table 7. Exterior wall R-value calculation for the "improved" building

Exterior Wall R-Value Calculation for "Improved" Building			
Component	**R-Value Studs**	**R-Value Cavity**	**Assembly R-Value**
Wall - Outside Air Film	0.17	0.17	
Siding - Wood Bevel	0.8	0.8	
3 1/2" Stud	4.38	0	
Polyisocyanurate (foil-faced)	0	25.2	
1/2" Drywall	0.45	0.45	
Inside Air Film	0.68	0.68	
Percent for 16" o.c. + Additional studs	15%	85%	
Total Wall R-Values	**6.48**	**27.3**	
Wall U-Values	**0.15**	**0.04**	
Total Wall R-Value			**18.42**

To improve the roof's energy performance and meet the REAP roof insulation standard of at least R-40, 4.5" of polyisocyanurate insulation was added to the assembly. Because the roof cross section did not currently detail any insulation in the current building, the rest of the assembly was kept the same. The resulting exterior wall R-value was 41.78 as seen in Table 8.

Table 8. Roof R-value calculation for the "improved" building

Roof R-Value Calculation for "Improved" Building			
Component	**R-Value Studs**	**R-Value Cavity**	**Assembly R-Value**
Wall - Outside Air Film	0.17	0.17	
Siding - Wood Bevel	0.8	0.8	
3 1/2" Stud	8.76	0	
Air space (between stud assemblies)	5	5	
Air space (within stud cavities)	0	2	
Polyisocyanurate (foil-faced)	32.4	32.4	
Asphalt Shingles	0.44	0.44	
Inside Air Film	0.68	0.68	
Percent for 16" o.c. + Additional studs	5.0%	95.0%	
Total Wall Component R-Values	**48.25**	**41.49**	
Wall Component U-Values	**0.0207**	**0.0241**	
Total Wall Assembly R-Value			**41.78**

4.2 Energy Performance

Once the R-values were determined and assigned to each of the assemblies considered for the current and improved buildings, the energy performance for each month over a year was calculated. Each month's energy use was calculated by determining the temperature difference between the outside temperature and room temperature, and multiplying this by the hours in a month and the area per unit R-value, as seen in Equation 2::

Equation 2:

$$Energy = \frac{(Temperature\ difference) * (Total\ area)}{(Weighted\ average\ R - value)} * (24\ {}^{hr}/_{day} * (Number\ of\ days))$$

Below, in Figure 13, the energy performances for the current and improved buildings are presented. As seen in the figure, the energy use of the improved building would be approximately 25% that of the current building.

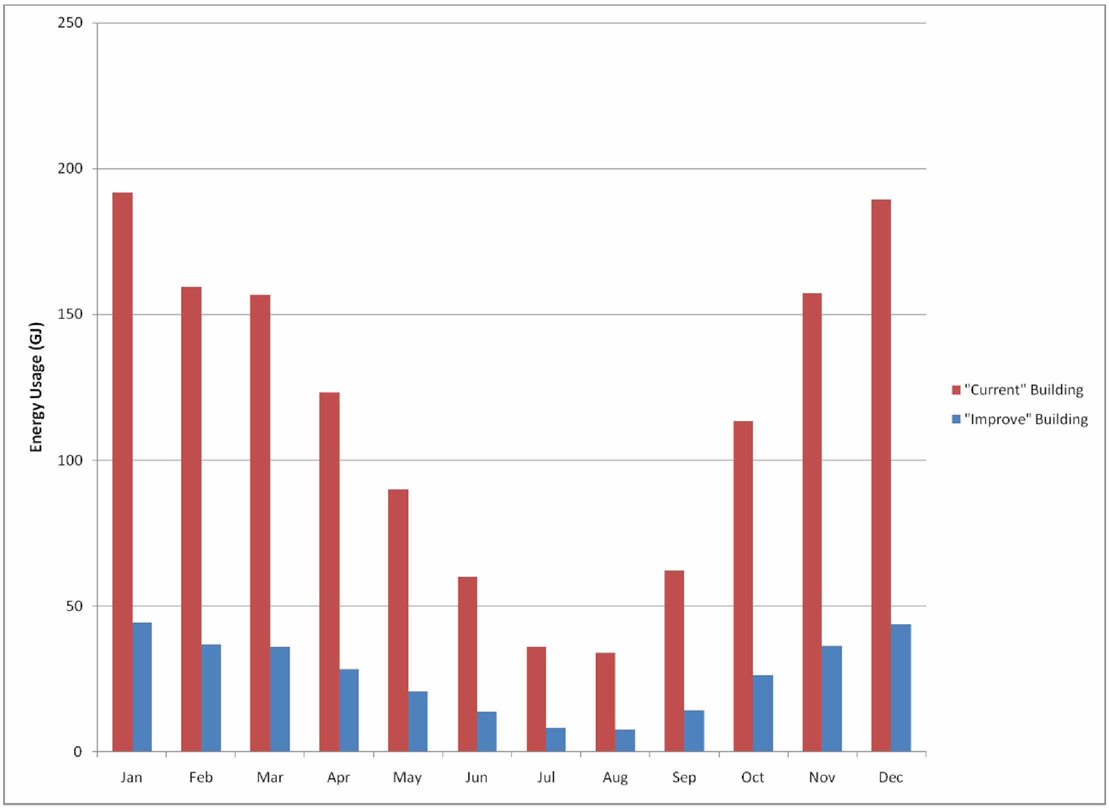

Figure 13. Energy usage per month for the current and improved Geography Building

The improved building was also modeled in the IE software. This was done by substituting the low E tin argon filled glazing for the standard glazing, and adding the specified polyisocyanurate insulation thicknesses to the roof and exterior walls. From the model, the primary energy consumption of the improved building was determined. This was then added to the cumulative energy use over 80 years—annual energy uses were determined by summing the monthly energy uses. The cumulative energy use over the 80 year span, including primary energy consumption, was then plotted for both buildings and plotted in Figure 14 below.

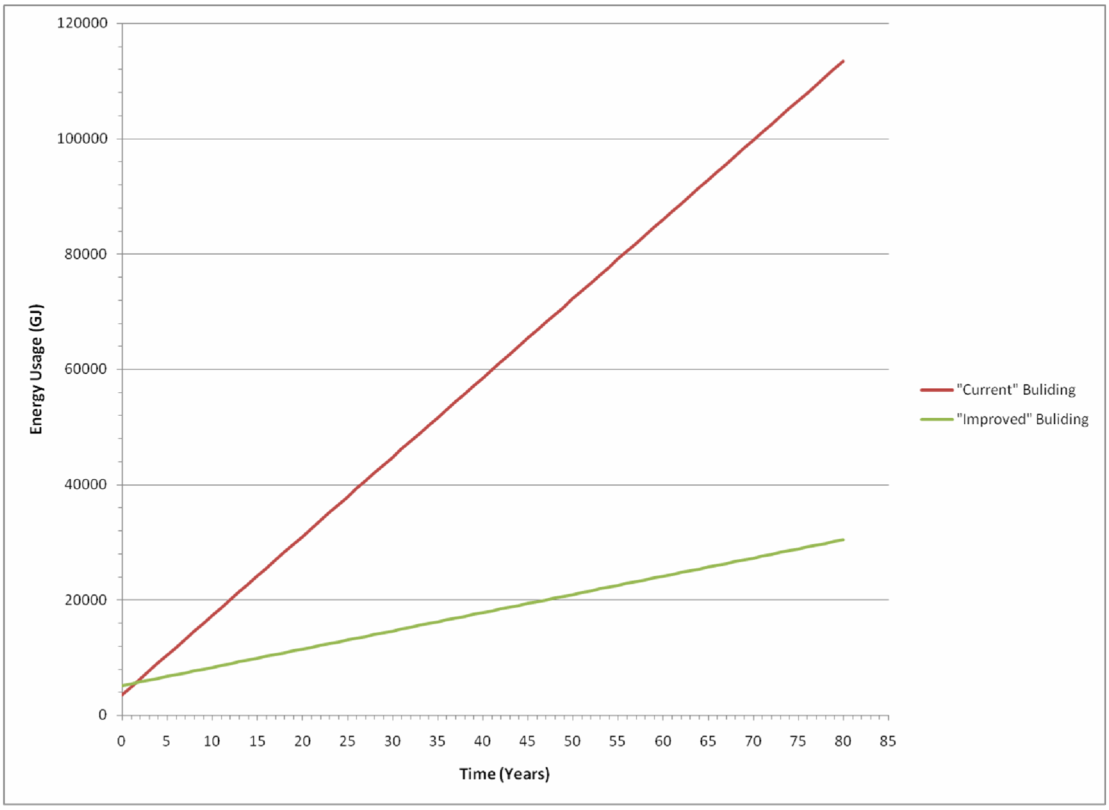

Figure 14. Energy Usage vs. Time for the current and improved Geography Building

It can be seen from the figure above that the total energy savings of the improved building over 80 years is approximately 80,000GJ. In addition, in Figure 15—a close up of the graph in Figure 14—it can be seen that the two energy use lines cross at approximately 1.5 years. This time is the energy payback period needed to “recover” the additional 1,600GJ of energy required to build the improved building.

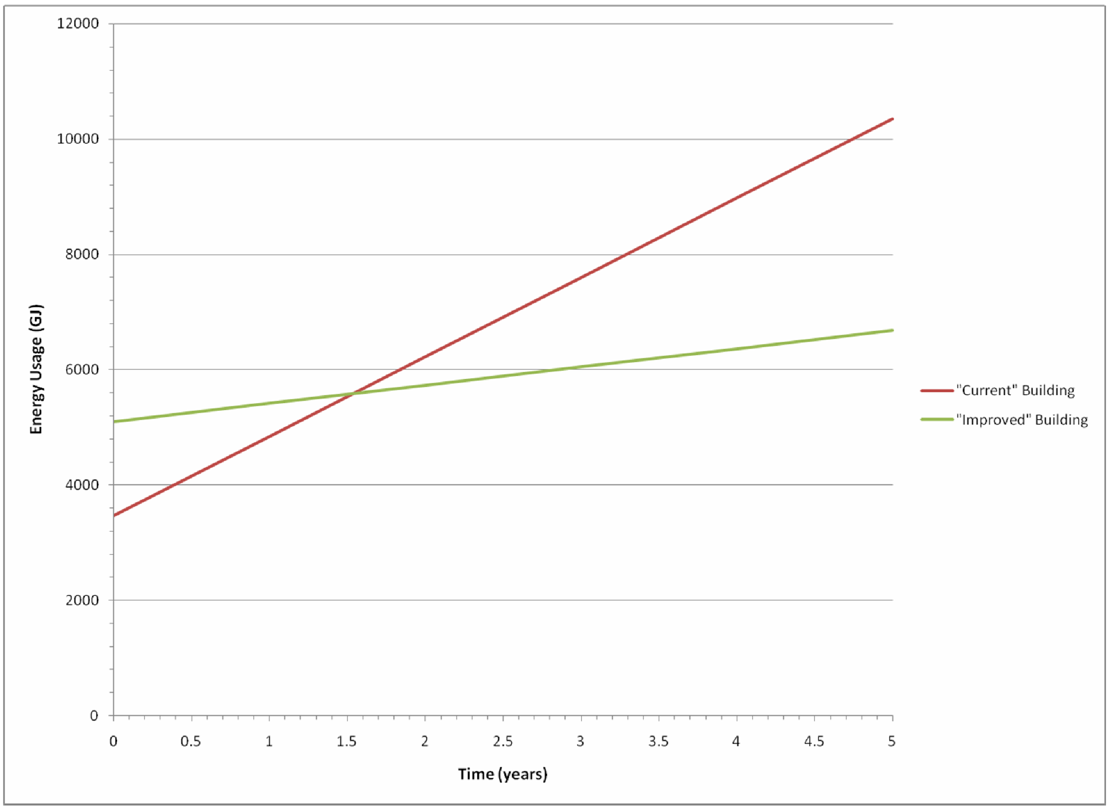

Figure 15. Close up of Energy Usage vs. Time for the current and improved Geography Building

4.3 Other Considerations

Although the above figure shows that the energy payback period for the improved building would be approximately 1.5 years, the actual energy payback period would likely be longer. This is because, in order to upgrade the current building, the lath and plaster walls would need to be removed and replace in order to install the insulation in the exterior walls. This is also true for installing insulation in the roof. It is also important to note that the economic payback period would most likely be longer than the energy payback period due to higher costs for better insulation and window glazing.

Finally, installing new windows and insulation would result in additional environmental impacts. In some cases, these impacts may outweigh the need to save energy. For this reason, it is important to do LCA's on the current and improved buildings when considering doing a building renovation. It can also be useful during the design stage to determine the materials and insulation that should be used.

5 Conclusion

After the building was modeled and the Bill of Materials was determined, it was found that the largest quantities of material by units of area were ½" regular gypsum board, softwood plywood, 6mil polyethylene, cedar wood shiplap siding, and stucco.

When the summary measures of the Geography Building were compared to those of an average academic building, it was found that the primary energy consumption, weighted resource use, global warming potential, acidification potential, human health respiratory effects potential, eutrophication potential, and smog potential ranged were below the average building impacts, and the ozone depletion potential was above that of the average building. It was then determined through sensitivity analysis that the ozone depletion potential was large in comparison due to the amount of plywood in the building.

Finally, through building performance calculations of the building's windows, exterior walls and roof, it was determined that adding 4.5" and 3.5" of polyisocyanurate insulation to the roof and exterior walls, respectively, and replacing all standard glazing windows with low E tin argon filled glazing to meet REAP insulation requirements would have a 1.55 year energy payback period.

Further studies in the LCA of the Geography Building could be completed by incorporating operational energy values to the model. In addition, doing a more detailed takeoff that includes permanent furniture within the Geography Building—including lab benches and lecture room desks—would provide further insight into the true impacts of the building. This modeling could be done not only for the original building, but also include renovations that have occurred over the past 85 years.

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Appendices

Appendix A: Impact Estimator Input Tables

ATHENA® Environmental Impact Estimator

General Description					
	Project Name		Geography		
	Project Location		Vancouver		
	Building Life Expectancy		60 years		
	Building Type		Institutional		
	Gross Floor Area (ft2)		51833		
	Operating Energy Consumption		-TBA-		
Assembly Group	**Assembly Type**	**Assembly Name**	**Input Fields**	**Input Values**	
				Known/Measured	EIE Inputs
1 Foundation					
	1.1 Concrete Footing				
		1.1.1 - 2'3" Concrete Footings			
			Length (ft)	175.500	175.500
			Width (ft)	2.250	2.250
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.2 - 2'9" Concrete Footings			
			Length (ft)	22.000	22.000
			Width (ft)	2.750	2.750
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.3 - 1'9" Concrete Footings			
			Length (ft)	267.750	267.750

			Width (ft)	1.750	1.750
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.4 - 2'3"x2'9" Concrete Footings			
			Length (ft)	16.500	16.500
			Width (ft)	2.250	2.250
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.5 - 3'3" Concrete Footings			
			Length (ft)	65.000	65.000
			Width (ft)	3.250	3.250
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.6 - 4'x4' Concrete Footings			
			Length (ft)	8.000	8.000
			Width (ft)	4.000	4.000
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.7 - Foundation Exterior Wall with Footings			
			Length (ft)	1091.000	1091.000
			Width (ft)	1.667	1.667
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.8 - Ground Entrance Stairs			
			Length (ft)	20.000	20.000
			Width (ft)	5.667	5.667
			Thickness (in)	8.000	8.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average

			Rebar	-	#4
		1.1.9 - Ground Entrance Stairs 2			
			Length (ft)	29.000	29.000
			Width (ft)	7.000	7.000
			Thickness (in)	12.000	12.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.10 - Ground Entrance Stairs 3			
			Length (ft)	7.500	7.500
			Width (ft)	3.000	3.000
			Thickness (in)	8.000	8.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
	1.2 Slab on Grade				
		1.2.1 - Foundation Concrete Floor			
			Length (ft)	34.438	34.438
			Width (ft)	16.000	16.000
			Thickness (in)	4.000	4.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
2 Custom Wall					
	2.1 Cast-in-Place				
		2.1.1 - Foundation Exterior Wall with Footings			
			Length (ft)	1091.000	1363.750
			Height (ft)	3.500	3.500
			Thickness (in)	10.000	8.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	Average
			Rebar	-	#5
		2.1.2 - Foundation Exterior Wall without Footings			
			Length (ft)	47.000	58.750
			Height (ft)	3.500	3.500
			Thickness (in)	10.000	8.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	Average
			Rebar	-	#5

	2.1.3 - Foundation 6" Interior Concrete Wall			
		Length (ft)	88.000	66.000
		Height (ft)	3.500	3.500
		Thickness (in)	6.000	8.000
		Concrete (psi)	-	4000.000
		Concrete flyash %	-	Average
		Rebar	-	#5
	2.1.4 - Foundation 8" Interior Concrete Wall			
		Length (ft)	342.000	342.000
		Height (ft)	3.500	3.500
		Thickness (in)	8.000	8.000
		Concrete (psi)	-	4000.000
		Concrete flyash %	-	Average
		Rebar	-	#5
	2.1.5 - Foundation 7" Interior Concrete Wall			
		Length (ft)	79.000	69.125
		Height (ft)	3.500	3.500
		Thickness (in)	7.000	8.000
		Concrete (psi)	-	4000.000
		Concrete flyash %	-	Average
		Rebar	-	#5
2.2 Wood Stud				
	2.2.1 - Ground Exterior Wall			
		Wall Type	Exterior	Exterior
		Length (ft)	1096.000	274.000
		Height (ft)	13.500	13.500
		Sheathing	None	None
		Stud thickness	2 x 6	2 x 6
		Stud Spacing	16 o.c.	16 o.c.
		Stud Type	Kiln dried	Kiln dried
	Window Opening	Number of Windows	332.000	83.000
		Total Window Area (ft2)	3229.722	807.431
		Frame Type	Wood	Wood
		Glazing Type	-	Standard Glazing
	Door Opening	Number of Doors	10.000	10.000
		Door Type	-	Solid Wood
	Envelope	Category	-	Gypsum board
		Material	Lath and Plaster	Gysum Regular 1/2"
		Thickness	-	-
		Category	Cladding	Cladding

			Material	Lath and Stucco	Stucco - Over porous sruface
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Shiplap	Wood Shiplap Siding - Cedar
			Thickness	-	-
		2.2.2 - First Floor Exterior Wall			
			Wall Type	Exterior	Exterior
			Length (ft)	1050.000	262.500
			Height (ft)	12.000	12.000
			Sheathing	None	None
			Stud thickness	2 x 6	2 x 6
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Window Opening	Number of Windows	334.000	83.500
			Total Window Area (ft2)	4024.583	1006.146
			Frame Type	Wood	Wood
			Glazing Type	-	Standard Glazing
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Lath and Stucco	Stucco - Over porous sruface
			Thickness	-	-
			Category	Cladding	Cladding
			Material	Shiplap	Wood Shiplap Siding - Cedar
			Thickness	-	-
		2.2.3 - Ground 2"x4" Stud Interior Wall			
			Wall Type	Interior	Interior
			Length (ft)	617.000	617.000
			Height (ft)	13.500	13.500
			Sheathing	-	None
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Door Opening	Number of Doors	21.000	21.000
			Door Type	-	Solid Wood
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-

			Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
		2.2.4 - Ground 2"x4" Stud Interior Wall with Steel Vestibule			
			Wall Type	Interior	Interior
			Length (ft)	17.000	17.000
			Height (ft)	13.500	13.500
			Sheathing	1/4" Ply. Both Sides	Plywood
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Door Opening	Number of Doors	1.000	1.000
			Door Type	Steel Vestibule	Steel Interior Door
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
		2.2.5 - Ground 2"x6" Stud Interior Wall			
			Wall Type	Interior	Interior
			Length (ft)	145.000	145.000
			Height (ft)	13.500	13.500
			Sheathing	-	None
			Stud thickness	2 x 6	2 x 6
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
		2.2.6 - Ground 2"x4" Stud Hallway Wall			
			Wall Type	Interior	Interior
			Length (ft)	919.000	919.000
			Height (ft)	13.500	13.500
			Sheathing	1/4" Ply. Both Sides	Plywood
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.

			Stud Type	Kiln dried	Kiln dried
		Door Opening	Number of Doors	44.000	44.000
			Door Type	-	Solid Wood
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
		2.2.7 - Ground 2"x4" Stud Lecture Room Wall			
			Wall Type	Interior	Interior
			Length (ft)	126.000	126.000
			Height (ft)	1.500	1.500
			Sheathing	1/4" Ply. Both Sides	Plywood
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
		2.2.8 - First Floor 2"x4" Stud Interior Wall			
			Wall Type	Interior	Interior
			Length (ft)	631.000	631.000
			Height (ft)	12.000	12.000
			Sheathing	-	None
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Door Opening	Number of Doors	16.000	16.000
			Door Type	-	Solid Wood
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	Gypsum board
			Material	Lath and Plaster	Gypsum Regular 1/2"
			Thickness	-	-
		2.2.9 - First Floor 2"x6" Stud Interior Wall			
			Wall Type	Interior	Interior

			Length (ft)	195.000	195.000
			Height (ft)	12.000	12.000
			Sheathing	-	None
			Stud thickness	2 x 6	2 x 6
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Door Opening	Number of Doors	7.000	7.000
			Door Type	-	Solid Wood
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
		2.2.10 - First Floor 2"x16" Stud Interior Wall			
			Wall Type	Interior	Interior
			Length (ft)	37.000	74.000
			Height (ft)	12.000	12.000
			Sheathing	-	None
			Stud thickness	2 x 16	2 x 8
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-
			Category	-	
			Material	Lath and Plaster	
			Thickness	-	
		2.2.11 - First Floor 2"x4" Stud Hallway Wall			
			Wall Type	Interior	Interior
			Length (ft)	704.000	704.000
			Height (ft)	12.000	12.000
			Sheathing	1/4" Ply. Both Sides	Plywood
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		Door Opening	Number of Doors	35.000	35.000
			Door Type	-	Solid Wood
		Envelope	Category	-	Gypsum board
			Material	Lath and Plaster	Gysum Regular 1/2"
			Thickness	-	-

			Category Material Thickness	- Lath and Plaster -	Gypsum board Gypsum Regular 1/2" -
		2.2.12 - Roof Area			
			Wall Type	Exterior	Exterior
			Length (ft)	63.000	63.000
			Height (ft)	68.000	68.000
			Sheathing	None	None
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		2.2.13 - Roof Area 2			
			Wall Type	Exterior	Exterior
			Length (ft)	50.000	50.000
			Height (ft)	19.000	19.000
			Sheathing	None	None
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		2.2.14 - Roof Area 3			
			Wall Type	Exterior	Exterior
			Length (ft)	17.300	17.300
			Height (ft)	61.000	61.000
			Sheathing	None	None
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
		2.2.15 - Roof Area 4			
			Wall Type	Exterior	Exterior
			Length (ft)	45.500	45.500
			Height (ft)	14.000	14.000
			Sheathing	None	None
			Stud thickness	2 x 4	2 x 4
			Stud Spacing	16 o.c.	16 o.c.
			Stud Type	Kiln dried	Kiln dried
3 Roofs					
	3.1 Wood Joist				
		3.1.1 - Roof Area			
			Roof Width (ft)	2577.500	2577.500
			Span (ft)	10.000	10.000
			Decking Type	-	None

			Live load (psf)	45.000	45.000
			Decking Thickness	-	1/2 in
		Envelope	Category	Vapour Barrier	Vapour Barrier
			Material	-	Polyethylene 6 mil
			Thickness (in)	-	-
			Category	Cladding	Cladding
			Material	Shiplap	Wood Shiplap Siding - Cedar
			Thickness (in)	-	-
			Category	Roof Envelopes	Roof Envelopes
			Material	Asphalt	Roofing Asphalt
			Thickness (in)	-	-
4 Floors					
	4.1 Suspended Slab				
		4.1.1 - Ground Concrete Floor			
			Floor Width (ft)	19.938	19.938
			Span (ft)	16.000	16.000
			Concrete (psi)	-	4000.000
			Live load (psf)	-	45.000
			Concrete flyash %	-	average
	4.2 Wood Joist Floor				
		4.2.1 - Ground Floor Area			
			Floor Width (ft)	2257.600	2257.600
			Span (ft)	10.000	10.000
			Decking Type	Wood	Plywood
			Live load (psf)	45.000	45.000
			Decking Thickness	-	1/2 in
		4.2.2 - First Floor Floor Area			
			Floor Width (ft)	2493.000	2493.000
			Span (ft)	10.000	10.000
			Decking Type	Wood	Plywood
			Live load (psf)	45.000	45.000
			Decking Thickness	-	1/2 in
		4.2.3 - Ground Sloped Lecture Room			
			Floor Width (ft)	253.200	253.200
			Span (ft)	10.000	10.000
			Decking Type	None	None
			Live load (psf)	45.000	45.000
			Decking Thickness	-	1/2 in
		4.2.4 - Ground Level Lecture Room			

			Floor Width (ft)	92.500	92.500
			Span (ft)	10.000	10.000
			Decking Type	Wood	Plywood
			Live load (psf)	45.000	45.000
			Decking Thickness	-	1/2 in
5 Extra Basic Materials					
	5.1 Wood				
		Total			
			Softwood Lumber (small dim., kiln dried) (Mbfm)	27.991	27.991
			Softwood Lumber (large dim., kiln dried) (Mbfm)	25.706	27.706
		5.1.1 - Ground 8"x18" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.444	1.444
		5.1.2 - Ground 8"x16" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	1.515	1.515
		5.1.3 - Ground 8"x14" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.345	0.345
		5.1.4 - Ground 6"x8" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.064	1.064
		5.1.5 - Ground 10"x16" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.507	0.507
		5.1.6 - First Floor 8"x14" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.345	0.345
		5.1.7 - First Floor 6"x10" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.170	0.170
		5.1.8 - First Floor 6"x8" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.116	0.116
		5.1.9 - First Floor 10"x16" Wood Beam			

			Softwood Lumber (large, kiln dried) (Mbfm)	1.667	1.667
		5.1.10 - First Floor 8"x16" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.896	0.896
		5.1.11 - First Floor 10"x18" Wood Beam			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.555	0.555
		5.1.12 - Foundation 6"x6" Wood Girder			
			Softwood Lumber (large, kiln dried) (Mbfm)	4.650	4.650
		5.1.13 - Foundation 6"x10" Wood Girder			
			Softwood Lumber (large, kiln dried) (Mbfm)	2.680	2.680
		5.1.14 - Foundation 6"x8" Wood Girder			
			Softwood Lumber (large, kiln dried) (Mbfm)	1.284	1.284
		5.1.15 - Foundation 6"x6" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	2.688	2.688
		5.1.16 - Foundation 8"x10" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	2.333	2.333
		5.1.17 - Foundation 8"x8" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.187	0.187
		5.1.18 - Ground 6"x8" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.540	0.540
		5.1.19 - Ground 8"x8" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.648	0.648
		5.1.20 - Ground 8"x10" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.810	0.810
		5.1.21 - First Floor 8"x8" Wood Post			

			Softwood Lumber (large, kiln dried) (Mbfm)	1.024	1.024
		5.1.22 - First Floor 6"x8" Wood Post			
			Softwood Lumber (large, kiln dried) (Mbfm)	0.384	0.384
		5.1.23 - First Floor Truss			
			Softwood Lumber (large, kiln dried) (Mbfm)	1.854	1.854
		5.1.24 - Ground Exterior Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	5.058	5.058
		5.1.25 - First Floor Exterior Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	3.811	3.811
		5.1.26 - Ground 2"x4" Stud Interior Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	3.528	3.528
		5.1.27 - Ground 2"x4" Stud Interior Wall with Steel Vestibule			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.094	0.094
		5.1.28 - Ground 2"x6" Stud Interior Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.870	0.870
		5.1.29 - Ground 2"x4" Stud Hallway Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	5.149	5.149
		5.1.30 - Ground 2"x4" Stud Lecture Room Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.084	0.084
		5.1.31 - First Floor 2"x4" Stud Interior Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	3.233	3.233
		5.1.32 - First Floor 2"x6" Stud Interior Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.982	0.982
		5.1.33 - First Floor 2"x16" Stud Interior Wall			

			Softwood Lumber (small, kiln dried) (Mbfm)	0.197	0.197
		5.1.34 - First Floor 2"x4" Stud Hallway Wall			
			Softwood Lumber (small, kiln dried) (Mbfm)	3.464	3.464
		5.1.35 - Ground Lecture Room Stairs			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.096	0.096
		5.1.36 - Ground Interior Stairs Up			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.139	0.139
		5.1.37 - FF Interior Stairs Down			
			Softwood Lumber (small, kiln dried) (Mbfm)	0.109	0.109
		5.1.38 - Ground Lecture Room			
			Softwood Lumber (small, kiln dried) (Mbfm)	1.178	1.178
	5.2 Steel				
		5.2.1 - First Floor Truss			
			Rebar Rod Light Sections (Tons)	0.360	0.360
			Cold Rolled Steel (Tons)	1.587	1.587

Appendix B: Impact Estimator Input Assumptions Document

6 Geography Assumptions

1. Foundation

Concrete footings were calculated using all three measurement conditions. Column footings on the foundation were measured using the count condition with the width and length provided from drawing 401-06-016, and the thickness provided from drawing 401-06-17. The strip footing below the exterior concrete wall was modeled using the width provided from drawing 401-06-016 and the linear condition used to measure the Foundation Exterior Wall with Footings. The concrete stairs on the ground level—which were modeled as footings and labeled as Ground Entrance Stairs—were measured using the area condition, with the average thickness estimated from the cross section as shown in drawing 401-06-020. Finally, Foundation Concrete Floor was modeled as a slab on grade using the area condition, with a thickness measurement of 4".

1.1 Concrete Footing

- Concrete strength was not given and was therefore assumed to be 4000psi
- Rebar was not given and was therefore assumed to be #4
- Concrete fly ash content was not given and was therefore assumed to be average

1.1.1 2'3" Concrete Footings

- Length of footing was calculated by multiplying the length of each footing by the number of footings of that type
  $2.25ft * 78 = 175.5ft$

1.1.2 2'9" Concrete Footings

- Length of footing was calculated by multiplying the length of each footing by the number of footings of that type
  $2.75ft * 8 = 22ft$

1.1.3 1'9" Concrete Footings

- Length of footing was calculated by multiplying the length of each footing by the number of footings of that type
  $1.75ft * 153 = 267.75ft$

1.1.4 2'3"x2'9" Concrete Footings

- Length of footing was calculated by multiplying the length of each footing by the number of footings of that type
  $2.75ft * 60 = 16.5ft$

1.1.5 3'3" Concrete Footings

- Length of footing was calculated by multiplying the length of each footing by the number of footings of that type
  $3.25ft * 20 = 65ft$

1.1.6 4'x4' Concrete Footings

- Length of footing was calculated by multiplying the length of each footing by the number of footings of that type
  $4ft * 2 = 8ft$

1.1.7 Foundation Exterior Wall with Footings

- Length of footing was given by the length takeoff from the Foundation Exterior Wall with Footings (2.1.1)

1.1.8 Ground Entrance Stairs

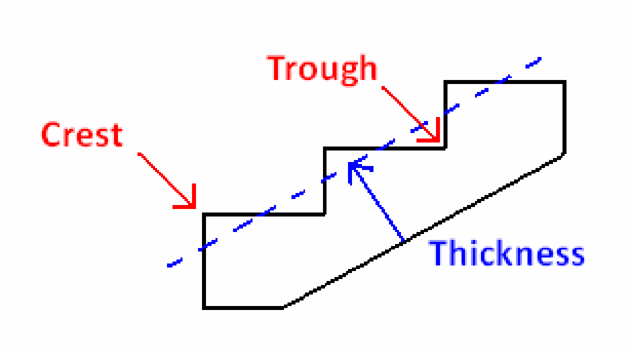
- Concrete thickness assumed to be linear by estimating the average thickness between the crest and the trough of the step, as seen below

1.1.9 Ground Entrance Stairs 2

- Concrete thickness assumed to be linear by estimating the average thickness between the crest and the trough of the step, as seen below

1.1.10 Ground Entrance Stairs 3

- Concrete thickness assumed to be linear by estimating the average thickness between the crest and the trough of the step, as seen below



1.2 Slab on Grade

1.2.1 Foundation Concrete Floor

- Concrete strength was not given and was therefore assumed to be 4000psi

- Concrete fly ash content was not given and was therefore assumed to be average

2. Custom Wall

The walls on the foundation, ground and first floor levels were modeled using linear conditions. The foundation concrete walls were assumed to have a height of 3.5’, based on an average of measurements from drawings 401-06-019 and 401-06-020. The exterior walls on the ground and first floors were modeled four times, due to limitations in the IE for number of windows. Hallway walls were also assumed to have plywood sheathing, based on drawing 401-06-030, a drawing from a building renovation in 1963. The doors and windows within the ground and first floor walls were modeled using count conditions. All doors, except for the steel vestibule which was assumed to be a 32”x7’ steel interior door, were assumed to be 32”x7’ solid wood doors. The windows were assumed to be fixed windows with standard glazing, and were modeled as wood frames based on site inspections.

2.1 Cast-in-Place

- Concrete strength was not given and was therefore assumed to be 4000psi
- Rebar was not given and was therefore assumed to be #5
- Concrete fly ash content was not given and was therefore assumed to be average

2.1.1 Foundation Exterior Wall with Footings

- Thickness of 10” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (10”/8”) for a total length of 1363.75’ to meet the concrete volume.
  $1091ft * (10''/8'') = 1363.75ft$

2.1.2 Foundation Exterior Wall without Footings

- Thickness of 10” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (10”/8”) for a total length of 58.75’ to meet the concrete volume.
  $47ft * (10''/8'') = 58.75$

2.1.3 Foundation 6" Interior Concrete Wall

- Thickness of 6” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (6”/8”)

for a total length of 66.0’ to meet the concrete volume.
$88ft * (10"/8") = 66ft$

2.1.5 Foundation 7" Interior Concrete Wall

- Thickness of 7” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (7”/8”) for a total length of 69.125’ to meet the concrete volume.
$79ft * (10"/8") = 69.125ft$

2.2 Wood Stud

2.2.5 Ground Exterior Wall

- Length of the wall was divided by 4 (and modeled 4 times) to accommodate limits on the number of windows

6.1.1.1 Window Opening

- Number of windows was divided by 4 (and modeled 4 times) to accommodate limits on the number of windows
- Total area of the windows was divided by 4 (and modeled 4 times) to accommodate limits on the number of windows
- Window glazing was not given and was therefore assumed to be standard glazing

6.1.1.2 Door Opening

- All 10 door openings were modeled in the first copy of the wall, and each subsequent four wall copies had 0 door openings
- Door material was not given and was therefore assumed to be solid wood
- All doors were assumed to have dimensions of 32”x7’

6.1.1.3 Envelope

- ½” regular gypsum board was used as a surrogate for plaster due to IE limitations
- Shiplap siding was assumed to be cedar given that the laths in the building are cedar as well
- Batten and paper were not modeled due to IE limitations

2.2.6 First Floor Exterior Wall

- Length of the wall was divided by 4 (and modeled 4 times) to accommodate limits on the number of windows

6.1.1.4 Window Opening

- Number of windows was divided by 4 (and modeled 4 times) to accommodate limits on the number of windows

- Total area of the windows was divided by 4 (and modeled 4 times) to accommodate limits on the number of windows
- Window glazing was not given and was therefore assumed to be standard glazing

6.1.1.5 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations
- Shiplap siding was assumed to be cedar given that the laths in the building are cedar as well
- Batten and paper were not modeled due to IE limitations

2.2.7 Ground 2"x4" Stud Interior Wall

6.1.1.6 Door Opening

- Door material was not given and was therefore assumed to be solid wood
- All doors were assumed to have dimensions of 32"x7'

6.1.1.7 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.8 Ground 2"x4" Stud Interior Wall with Steel Vestibule

Door Opening

- Steel vestibule was assumed to be steel interior door with dimensions of 32"x7'

6.1.1.8 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.9 Ground 2"x6" Stud Interior Wall

Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.10 Ground 2"x4" Stud Hallway Wall

Door Opening

- Door material was not given and was therefore assumed to be solid wood

6.1.1.9 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.11 Ground 2"x4" Stud Lecture Room Wall

- This wall was added to accommodate the additional wall height within the lecture room
- A height of 1.5' was assumed as the average increased wall height

6.1.1.10 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.12 First Floor 2"x4" Stud Interior Wall

Door Opening

- Door material was not given and was therefore assumed to be solid wood

6.1.1.11 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.13 First Floor 2"x6" Stud Interior Wall

Door Opening

- Door material was not given and was therefore assumed to be solid wood

6.1.1.12 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

2.2.14 First Floor 2"x16" Stud Interior Wall

- Stud thickness of 2"x16" was given, however 2"x8" was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (16"/8") for a total length of 74' to meet the concrete volume
  $37ft * (16"/8") = 74ft$

6.1.1.13 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

- Gypsum board was only modeled once due to doubling in the wall length

2.2.15 First Floor 2"x4" Stud Hallway Wall

Door Opening

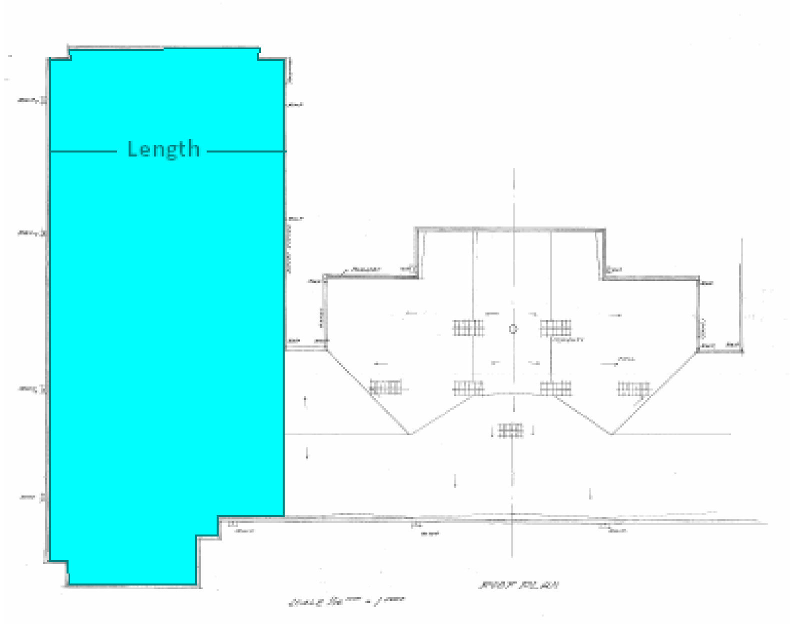
- Door material was not given and was therefore assumed to be solid wood

6.1.1.14 Envelope

- ½" regular gypsum board was used as a surrogate for plaster due to IE limitations

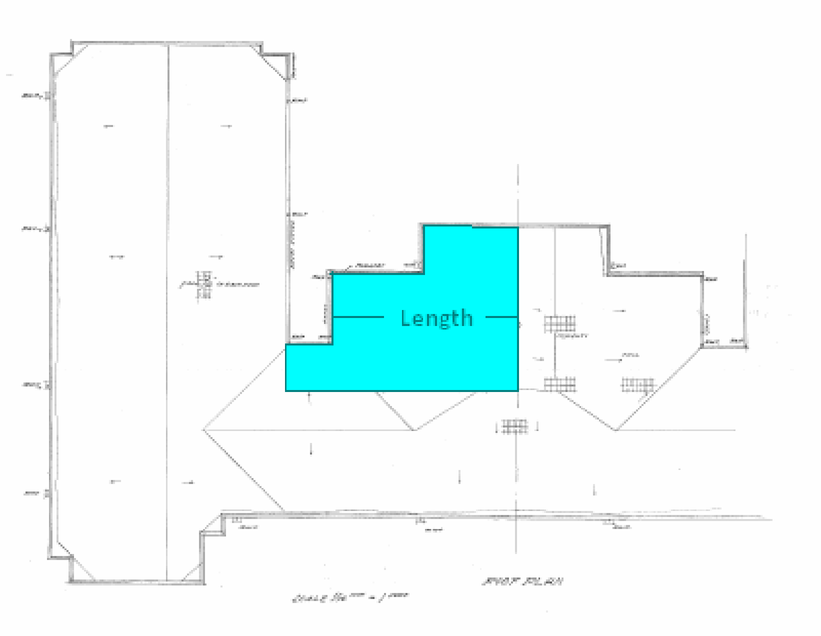
2.2.16 Roof Area

- Width of roof area given by dividing the highlighted area by the length, as shown below
- Area modeled twice to account for symmetric design



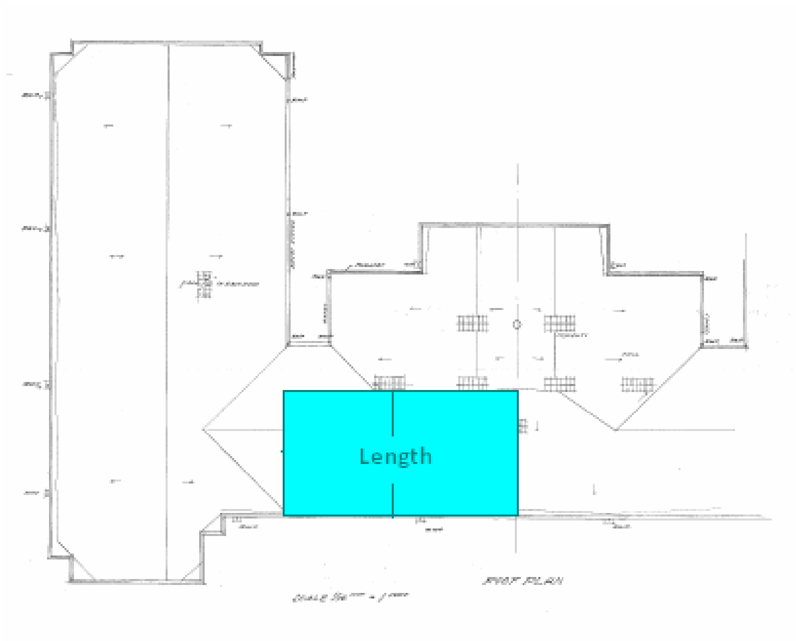
2.2.17 Roof Area 2

- Width of roof area given by dividing the highlighted area by the length, as shown below
- Area modeled twice to account for symmetric design



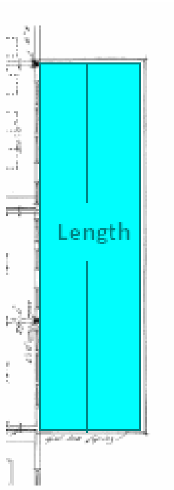
2.2.18 Roof Area 3

- Width of roof area given by dividing the highlighted area by the length, as shown below
- Area modeled twice to account for symmetric design



2.2.19 Roof Area 4

- Width of roof area given by dividing the highlighted area by the length, as shown below



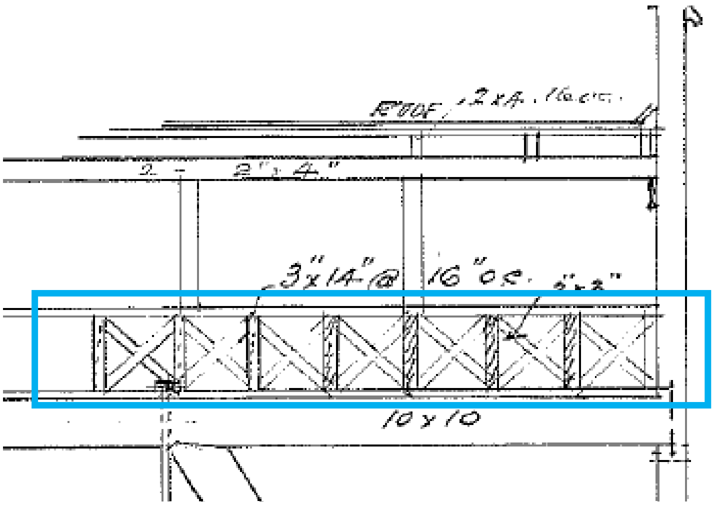
3. Roofs

The roof of the building was made up of two wood joist sections, as seen below. The lower portion was modeled as a wood joist roof, while the upper portion was modeled as 4 separate wall sections with 2”x4” wood studs. Sloped sections of the “wall sections” were assumed to be flat.

3.1 Wood Joist

3.1.5 Roof Area

- Spans were assumed to be 10ft due to IE limitations
- This roof area modeled the lower portion of the roof, as highlighted below (Note: the top portion of the roof was modeled as wall sections as seen in 2.2.12-2.2.15)



6.1.1.15

6.1.1.16 Envelope

- Roofing asphalt assumed based on known asphalt roof
- Polyethylene 6mil vapour barrier assumed

4. Floors

The floors were modeled using the area condition. An assumed live load of 45psf also used based on drawing 401-07-001, a list of specifications from a 2004 renovation. The wood joist floors were assumed to have ½” thick plywood decking based on knowledge of the decking being wood. Finally, the sloped section of the lecture room was modeled to have a slope based on the dimensions of the risers and treads of the steps, as seen in drawing 401-06-019. A sloped wood joist floor was modeled, and the addition material used for the steps was added as extra basic material.

4.1 Slab on Grade

4.1.5 Ground Concrete Floor

- Concrete strength was not given and was therefore assumed to be 4000psi
- Live load assumed to be 45psf based on live load for roof and first floor
- Concrete fly ash content was not given and was therefore assumed to be average
- Span assumed to be 16ft due to IE limitations

4.2 Wood Joist Floor

- Floors were assumed to have ½" plywood decking
- Spans were assumed to be 10ft due to IE limitations

4.2.3 Ground Sloped Lecture Room

- No plywood decking was added to this floor area because the steps were modeled using extra wood (5.1.35)

5. Extra Basic Materials

5.2 Wood

- Volumes of beams, posts and girders were calculated based on given dimensions and modeled length, and converted into Mbfm

$$(w'' * d'' * l') * (12in/ft)/(1000bfm/Mbfm) = V\ Mbfm$$

- Total lath volumes for the exterior and interior walls were calculated by multiplying the calculated lath volume per 1'x1' area—as seen below with assumed lath dimensions and spacing—by the twice the total area of the wall, to account for laths on both sides of the walls

Dimensions	Spacing	Boards per 4'x4'	Boards per 1'x1'	Volume per Board (fbm)	Volume per 1'x1' (fbm)
4'x2"x1/4"	1/4"	21.333	1.333	0.167	0.222

5.1.23 First Floor Truss

- Extra wood for the first floor truss was calculated at seen in the table below

#	Material	Dimension	Length/Height (ft)	Area (sqft)	Volume (fbm)	Rise	Run	Total Volume
1	Wood Tie Beam	10"x10"	51.00	42.50	425.00	0.00	51.00	425.00
1	Wood Tie Beam	10"x12"	51.00	51.00	510.00	0.00	51.00	510.00
2	Wood Post	10"x12"	13.50	13.50	135.00	13.50	0.00	270.00
2	Diagonal Posts	10"x12"	15.05	15.05	150.46	12.50	8.38	300.93
2	Diagonal Posts	10"x8"	14.98	9.98	99.85	12.50	8.25	199.69
2	Diagonal Posts	10"x6"	14.84	7.42	74.20	12.50	8.00	148.41
	Total V =	1854.03 fbm						

5.1.35 Ground Lecture Room Stairs

- Steps were assumed to have dimensions of 7’x½”
- Stringer board (or diagonal) assumed to have dimensions of 2”x8”
- Volumes were calculated based on wood dimensions and lengths, and were doubled to accommodate identical stairwells (Note: Lengths of treads, risers and diagonals given below)

	# of Steps	Tread (in)	Rise (in)	Diagonal (ft)	Volume (fbm)
1st Flight	8	10	6	8	48

5.1.36 Ground Interior Stairs Up

- Steps were assumed to have dimensions of 5.5’x½”
- Stringer board (or diagonal) assumed to have dimensions of 2”x8”
- Volumes were calculated based on wood dimensions and lengths, and were doubled to accommodate identical stairwells (Note: Lengths of treads, risers and diagonals given below)

	# of Steps	Tread (in)	Rise (in)	Diagonal (ft)	Volume (fbm)
1st Flight	14	10	6	13.5	69.33

5.1.37 FF Interior Stairs Down

- Steps were assumed to have dimensions of 5.5’x½”
- Stringer board (or diagonal) assumed to have dimensions of 2”x8”
- Volumes were calculated based on wood dimensions and lengths, and were doubled to accommodate identical stairwells (Note: Lengths of treads, risers and diagonals given below)

	# of Steps	Tread (in)	Rise (in)	Diagonal (ft)	Volume (fbm)
2nd Flight	11	10	6	10.5	54.33

5.1.38 Ground Lecture Room

- Steps were assumed to have dimensions of 50’x½”

- Volumes were calculated based on wood dimensions and lengths (Note: Lengths of treads and risers)

	# of Steps	Tread (in)	Rise (in)	Volume (fbm)
1st Flight	12	34	7	1178

5.2 Steel

5.2.1 First Floor Truss

- Extra steel for the first floor truss was calculated at seen in the table below
- Rods were assumed to be “Rebar Rod Light Sections”
- Plates were assumed to be “Cold Rolled Sheet”

#	Material	Dimension	Length/Height (ft)	Area (sqft)	Volume (fbm)	Total Volume
2	Rod (End upset)	2"	13.500	0.022	0.295	0.589
2	Rod (End upset)	1.5"	13.500	0.022	0.295	0.589
1	Rod (End upset)	1.25"	13.500	0.022	0.295	0.295
	Total V=	1.473	ft3			
	Total W=	720.147	lbs			
	Total W=	0.360	tons			

6.1.1.17

#	Material	Dimension	Length/Height (ft)	Area (sqft)	Volume (fbm)	Total Volume
2	Plate	1/2"x10"	5.750	4.792	2.396	4.792
6	Plate	3/8"x3"x10"	-	0.208	0.078	0.469
4	Plate	8"x8"x3/8"	-	0.444	0.167	0.667
6	Plate	6"x6"x3/8"	-	0.250	0.094	0.563
	Total V=	6.490	ft3			
	Total W=	3173.562	lbs			
	Total W=	1.587	tons			

6.1.1.18