Life Cycle Analysis Study of the Hennings Building at the University of British Columbia

Author: Robyn Edgar

Department: Civil Engineering

Date: March 27, 2009

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Introduction

The Hennings building is located at 6224 Agricultural Road on the UBC Vancouver campus. The building can be found at the intersection of Agricultural Road and East Mall. The main entrance is on the north end of the building off of Agricultural Road.

The building was erected in 1945 and was simply named the Physics Building. It was the first permanent building constructed on campus since 1925. The building was renamed in 1963 in honour of UBC Professor Dr. A.E. Hennings (instructor from 1920 to 1948).

The main structural material used was concrete. It was used extensively in the foundations, the exterior walls, the roof, and in the beams and columns. The exterior of the building also includes a granite veneer on a portion of the concrete face.

The structure's main function was an educational and institutional building. The building includes one 272 seating capacity lecture theatre, two 140 person lecture theatres, and 5 instructional rooms. The laboratory space in the building includes 12 physics labs, 11 small research labs, 2 large research labs, 3 electrical labs, 1 high tension lab, 1 optics lab, and 1 x-ray lab. The building also includes 12 instructors' offices, one administration office, one library, one mechanical/electrical/wood shop, and one apparatus room.

Table 1: Building Characteristics

Building System	**Specific Characteristics**
Foundation	Continuous wall foundations and column foundations both of varying widths and thicknesses
Exterior Walls	10" cast in place walls with 2" X 4" wood stud wall on interior with 2" rock wool
Load Bearing Walls	6", 8", 10" cast in place concrete walls
Partition Walls	cast in place concrete in basement, 2" X 4" wood frame and curtain on upper stories
Windows	Single glazed, wood frame windows
Beams and Columns	Concrete beams and columns at varying bays and spans
Roof	Flat concrete roof modelled as double T with large light well in centre of building
Floors	Floating slab on basement level, suspended slab on 1st and 2nd floor
HVAC/heating	Steam heated using natural gas

Goal and Scope

Goal of Study

This life cycle analysis (LCA) of the Hennings Building at the University of British Columbia (UBC) was carried out as an exploratory study to determine the environmental impact of its design. This LCA was also part of a series of twelve other LCAs being carried out simultaneously on respective buildings at UBC with the same goal and scope.

The main outcomes of this LCA study were the establishment of a materials inventory and the assessment of the environmental impact of the Hennings Building. An exemplary application of these references is in the assessment of potential future performance upgrades to the structure and envelope systems of the Hennings Building. When this study is reviewed in conjunction with the twelve other UBC building LCA studies, further applications include the possibility of carrying out environmental performance comparisons across the UBC buildings over time and between the different building materials, the structural types, and the building functions. Furthermore, as demonstrated through these potential applications, this Hennings 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 the individuals involved in policy making as it relates to building development at UBC. One such group located on campus would be the Sustainability Office. They are involved in creating policies and frameworks for sustainable developments on campus. Other potential audiences include: developers, architects, engineers, and building owners involved in design planning. This study is also intended for external organizations such as government bodies, private industry, as well as, other universities whom may want to learn more or become engaged in performing similar LCA studies within their organizations.

Scope of Study

The product systems being studied in this LCA are the structural system, the building envelope system. The operational energy usage associated with space conditioning of the Hennings Building was also assessed. This study was conducted on a per square foot of the finished floor area of academic building basis. In order to focus on the design related impacts, this LCA encompassed a cradle-to-gate scope that includes the raw material extraction, the manufacturing of the construction materials, and the construction of the structure and envelope of the Henning Building, as well as the associated transportation effects throughout.

The primary sources of data for this LCA were the original architectural and structural drawings from when the Hennings Building was initially constructed in 1945. The assemblies of the building that were modeled included the foundation, the columns and beams, the floors, the walls, and the roof. This also included the associated building envelope and various openings (i.e. doors and windows) within each of these assemblies. A decision was made to omit other building components, such as, the flooring, the electrical aspects, the HVAC system, the finishing, the detailing, etc. This choice was associated with the limitations of the 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 lacked sufficient material details, which necessitated the usage of assumptions to complete the modeling of the building in the software. Furthermore, there are inherent assumptions made by the software in order to generate the bill of materials and there are limitations to what it can model. This necessitated further assumptions to be made. These assumptions and limitations will be discussed further in the Building Model section. All specific input related assumptions are contained in the Input Assumptions document in Appendix B.

The two main software tools being utilized to complete this LCA study were OnCenter's OnScreen TakeOff (OST) version 3.6.2.25 and the Athena Sustainable Materials Institute's Impact Estimator (IE) for Buildings version 4.0.51.

On-Screen Takeoff

OST is a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. By using imported digital plans, the program simplifies the calculations and measurements required to complete the takeoff process. In doing so, it also reduces the error associated with these two activities.

The study first undertook the initial stage of a materials quantity takeoff, which involved performing linear, area, and count measurements of the building's structure and envelope using OST. The measurements generated were 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.

Athena Impact Estimator

The IE software used in this analysis was the only available software capable of meeting the requirements of this study. 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.

Using the formatted takeoff data, the IE was used to generate a whole building LCA model for the Hennings Building in the Vancouver region as an Institutional building type. 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 Hennings Building was set to one year. This allows for the maintenance, the operating energy and the end-of-life stages of the building's life cycle being left outside the scope of assessment.

The IE filters the LCA results through a set of characterization measures, or summary 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 Hennings Building, all of the available TRACI impact assessment categories available in the IE were included in this study, and are listed as;

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

Using the summary measure results, a sensitivity analysis was then conducted in order to reveal the effects of material changes on the impact profile of the Hennings Building. Finally, using the UBC Residential Environmental Assessment Program (REAP) as a guide, this study then estimates the embodied energy involved in upgrading the thermal resistivity of the building. The insulation and window were modeled at R-values at REAP standards and energy payback period for investing in a better performing envelope was calculated.

Building Model

Takeoffs

The takeoffs were generated based on the data obtained from a variety of sources. The majority of the data was obtained from the original structural and architectural design drawings. Additional information was gathered from the Records Department at UBC. The design drawings of the time period were drawn up by hand. This made some of the values hard to read and some reasonable assumptions had to be made when this was the case. A note was made for all values that were assumed in this fashion. It was also found that most data on the building materials used was not recorded on the drawings. By inputting materials that were commonly used at the time of construction, reasonable assumptions were made.

Foundations

There were three components to the building foundation that were input into the Impact Estimator. There was the floor slab, the bearing wall foundations, and the column foundations. The stairs in the building were also modelled as foundation slabs because of the inputs available for foundation slabs.

The floor slab (1.1.1) was modelled as a continuous slab although there were slight elevation variations around the basement level. This was viewed as a reasonable assumption since the floor slab was consistently shown to be 4 inches thick regardless of the grade differences.

The bearing wall foundations (1.2.1 – 1.2.7) were modelled based on the wall thickness and the footing width. Any exterior bearing wall foundations were also modelled separately from any interior wall foundations. This allowed for a more robust model and also simplified the analysis by allowing these takeoffs to be used in the wall section below.

The column foundations (1.2.8 – 1.2.12) were modelled as continuous footings to simplify the inputs into the IE. They were input as being the specified footing width and a length equal to the number of columns multiplied by the width of the column. This allowed them to be modelled as a continuous wall foundation as well.

There were three sets of stairwells in the building. The inclined length of the stairways was used as the slab length. The width of the stairwell as input as the slab width and the average thickness of the stair slab was input as the slab thickness. The stairway lengths can be reviewed in OST of drawings 652-07-016 and 652-07-017.

Walls

The walls in the Hennings Building were either cast-in-place concrete walls, curtain walls, or wood stud walls.

Because of the differing envelope materials, the interior and exterior cast-in-place walls were modelled separately. If the walls were a different thickness, they were also modelled separately. The basement had the most inputs for concrete walls because of the various thicknesses of the load bearing walls specified. If the wall was designed to be 10 inches thick, it was modelled at 12 inches to match the available IE inputs. The wall was given a shorter length to compensate for the volume of material. This was also true for a 6 inch thick wall modelled as 8 inches thick due to the same constraint. These assumptions on the exterior walls required the addition of a wood stud wall (2.3.4) to account for the actual wall length.

The exterior walls were modelled as being 12" cast in place concrete (2.1.1, 2.1.2, 2.1.3, 2.1.9, 2.1.91, 2.1.92, 2.1.11, 2.1.111) with 2"x4" wood frame walls (2.1.1a, 2.1.2a, 2.1.3a, 2.1.9a, 2.1.91a, 2.1.92a, 2.1.11a, 2.1.111a) on the interior face of the concrete wall. This wood frame wall was shown on the architectural design drawings (652-06-065) and was assumed to house the thermal insulation. Although, no insulation was specified on the drawings, research showed that the most likely insulation material was Rockwool insulation of minimal thickness (Lotz, 2006). This was modelled as Rockwool insulation of two inch thickness producing an R-value of 6.28.

The exterior walls on the 1st and 2nd floor (2.1.9, 2.1.11) contained more than 100 windows. These walls had to be split up into wall segments (2.1.91, 2.1.92, 2.1.111) containing a maximum of 100 windows due to a build 51 known issue.

The exterior wall that faces the light well on the 2nd storey (2.3.5) was shown in the 2nd floor architectural drawing (652-06-067) to be of wood stud construction. It was modelled as a 2"x6" wood stud wall with 2 inches of Rockwool insulation. The windows in this wall input were counted and input into the IE.

The interior partition walls (2.3.1, 2.3.2, 2.3.3) were modelled as 2"x4" wood frame walls. All lumber used in the design was green timber, common for the time period. Also, no sheathing material was used in the model as lateral bracing was achieved with the reinforced concrete frame of the structure.

The curtain walls (2.2.1, 2.2.2) were assigned to their appropriate floor plan. No information was available regarding the glazing to spandrel ratio. The glazing was assumed to be 70% with 30% assumed to be spandrel.

The exterior walls were assumed to have ½" gypsum board wall coverings on the interior face of the wall. The interior walls were modelled with ½" gypsum board on both wall faces. The original interior wall material was not stated, but was most likely a plaster on lathe system. The wall material was modelled as gypsum board since this is the closest equivalent material offered by the IE.

A small portion of the northern exterior building face contained a granite veneer. Since the quantity of granite was not substantial and a suitable substitute was not available in the IE, this exterior finish was excluded from the LCA.

Beams and Columns

The lengths of the beams in the building varied from span to span. The lengths were averaged depending on a variety of bay sizes. The design live load on the first floor was 60psf and this was modelled as 75psf, because it was the closest value offered by the IE. The design live load on the second floor was 40psf and was modelled at 45psf for the same reason.

The columns were numbered by the structural designer. The number of columns in the building was determined by the largest column count found in the North West corner of the structural design drawings (652-07-005 through 652-07-007).

Roof

The roof was modelled as a precast double T. Although the actual roof structure was not stated on the design drawings, the roof structure was concrete; therefore, this roof structure allowed for a reinforced concrete roof structure close to what was designed. It was noted that building practices of the time would not have facilitated such pre-cast construction. This roof structure was still appropriate since the concrete was produced and it was transported to the site in some fashion and that impact was accounted for in this condition.

The roof area was calculated as a rectangular slab of equal area as the building footprint. This roof slab included the light well slab over the large lecture theatre on the 1st storey. This was done to simplify the inputs without compromising the accuracy of the model. The bay and span sizes were measured off the structural roof drawing (652-07-008) and were average at 20ft and 30ft, respectively. The number of bays on the roof was determined based on the information gathered according to the following formula:

Equation 1: Roof Area = Number_of_Bays * Bay_Size * Span_Size

Floors

All of the floors in the building were modelled as suspended slabs. Since the basement floor was modelled as a foundation slab, there were only the 1st and 2nd floor to model under the floors heading. The design live loads were collected from the structural design drawing 652-07-005. They were found to be 100psf and 60psf for the 1st and 2nd storey, respectively. The first floor was modelled at the 100psf design load as this option was available in the software. The second storey was modelled at 75psf because it was the closest available option in the IE software.

For the 1st storey floor, it was assumed that the lecture hall floors were all at the same elevation. In reality, the lecture hall was constructed with step joists to allow for theatre-type seating. It was found that this gave a similar result to modelling the 3 lecture halls separately. Thus, for simplicity, the first floor slab is modelled as a standard suspended slab.

The second storey floor slab area was calculated as being the total footprint area minus the light well area. This was modelled as a suspended slab.

The floor inputs in the IE allowed for a maximum floor span of 30ft. To account for this restriction, the floor length was modified to achieve the equivalent square footage. The floor length was calculated as the gross floor area divided by the maximum 30ft span.

Bill of Materials

Athena Impact Estimator generated a bill of materials (BOM) for the construction of the Hennings Building. Table 2 shows the estimated bill of materials needed to construct the building. It was difficult to compare the quantity of various materials with each other due to the different units of measurement used.

The concrete quantity was substantial because it was the structural building material chosen for the building. The majority of the concrete used in the building (149348.6 ft^3) had a maximum compressive strength of 3000 psi after 28 days of curing. This concrete was used in all the foundations, the floor slabs, and the walls.

The extensive use of concrete in the structure also lead to a large quantity of reinforcing steel utilized in the concrete members to sustain any tension and/or shear loading. The IE quoted 248.9 US tons of rebar.

By estimating the roof assembly as a pre-cast double T system, the IE approximated 2590.4lbs of EPDM waterproof membrane. It is more likely that the assembly was a tar and gravel roof. This input was limited to the materials that the IE provided and EPDM was chosen.

One of the largest quantities in the BOM was the estimated quantity of gypsum board at 236717.3 ft^2. When the building was constructed, the wall finishing would have been a plaster material on a wooden backdrop. Since the IE offers only modern building materials in the program, the building was assumed to have gypsum walls. This showed that the wall assemblies contributed significantly to the materials required.

Another significant quantity was the Rockwool insulation, 58677.5 ft^2 (1 inch). This quantity had some uncertainty associated with it because the information available did not provide any reference to an exterior wall insulation material. The architectural drawings showed a wood stud wall built adjacent to the exterior cast in place wall. The only foreseeable reason to install the wood stud wall was for insulation purposes. Since buildings were not heavily insulated in the 1940's and insulation research was only just beginning (Lotz, 2006), the insulation thickness was estimated as being relatively thin, 2 inches, to current standards. Also, the installation methods were not extensively developed at this time, this would lead to air spaces between the batt insulation and the wall studs.

Table 2: Hennings Building - Bill of Materials

	SI		Imperial	
Material	Quantity	Unit	Quantity	Unit
1/2" Regular Gypsum Board	21991.8	m2	236717.3	ft2
Aluminium	23.6	Tonnes	26.0	US ton
Batt. Fiberglass	7.1	m2 (25mm)	76.2	ft2 (1 inch)
Batt. Rockwool	5451.3	m2 (25mm)	58677.5	ft2 (1 inch)
Concrete 20 MPa (flyash av)	4229.1	m3	149348.6	ft3
Concrete 30 MPa (flyash av)	608.7	m3	21495.7	ft3
Concrete 60 MPa (flyash av)	338.2	m3	11944.2	ft3
EPDM membrane	1175.0	Kg	2590.4	lb
Galvanized Sheet	1.1	Tonnes	1.2	US ton
Glazing Panel	13.4	Tonnes	14.8	US ton
Joint Compound	21.9	Tonnes	24.2	US ton
Nails	2.7	Tonnes	2.9	US ton
Paper Tape	0.3	Tonnes	0.3	US ton
Rebar, Rod, Light Sections	225.8	Tonnes	248.9	US ton
Screws Nuts & Bolts	0.2	Tonnes	0.2	US ton
Small Dimension Softwood Lumber, Green	132.3	m3	4672.2	ft3
Small Dimension Softwood Lumber, kiln-dried	15.0	m3	530.4	ft3
Standard Glazing	927.4	m2	9982.3	ft2
Water Based Latex Paint	128.2	L	33.9	gal us
Welded Wire Mesh / Ladder Wire	8.1	Tonnes	9.0	US ton

Summary Measures

In the LCA of the Hennings Building all of the summary measures available in the IE were analyzed. These measures include the primary energy consumption, the weighted raw resource use, the global warming potential, the acidification potential, the human health respiratory effects potential, the eutrophication potential, the ozone depletion potential, and the photochemical smog potential.

The primary energy quantity includes all the direct and indirect energy used to manufacture and ship the building materials. The manufacturing process takes into account the energy required to transport and transform the raw materials into construction materials. The inherent energy contained in the raw or feedstock materials were also used as energy sources. The indirect energies accounted for in the primary energy value were those associated with processing, transporting, converting, and delivering the fuel and energy. (Athena)

The weighted resource use measure took into account "...the relative effects of different resource extraction activities" (Athena). The value quoted was the sum of the weighted resource requirements for all of the products used in the Hennings Building. The output was converted to a weight measurement according Equation 1. The respective weights in the formula correspond to the "...expert opinion about the relative ecological carrying capacity effects of extracting [the] resources" (Athena).

Equation 2: Resource Use = $(M_{Fossil\ Fuels})(1.0) + (M_{Limestone})(1.5) + (M_{Iron\ Ore})(2.25) + (M_{Coal})(2.25) + (M_{Wood\ Fiber})(2.5)$

The global warming potential is a reference measure based on equivalent CO_2. The carbon dioxide discharge is the reference emission. All other emissions that contribute to global warming effects are then multiplied by their corresponding weighting factor to convert them into CO_2 equivalence. The chemical lifetime is also an important consideration when analysing global warming effects. TRACI has used the International Panel on Climate Change 100-year time horizon for converting emissions into CO_2 equivalence. "While greenhouse gas emissions are largely a function of energy combustion, some products also emit greenhouse gases during the processing of the raw materials." (Athena) The most significant example of emissions during processing is the production of cement for concrete construction. Global warming causes environmental damage through coastal area damage, agricultural effects, forest damage, and plant and animal effects. (Athena)

The acidification potential quantifies the potential to cause wet or dry acid deposits. This is a more regional impact due to the reduced travel potential. It is quantified in H^+ equivalence based on mass. Acidification mainly effects human health especially in high concentrations of NO_X and SO_2. This value can also have effects on plants, animals, and the local ecosystem. (Athena)

The human health (HH) respiratory effects potential considers the impacts of particulate matter on human health. Small particulate matter (PM_{10} and $PM_{2.5}$) have considerable impacts on human health. They are a major cause of asthma, bronchitis, and acute pulmonary disease. Some major sources of particulate matter are in diesel fuel combustion and in plywood product production. The impacts stated in this report are stated as $PM_{2.5}$ equivalence. (Athena)

The eutrophication potential is a measure of the increase in chemical nutrients into the ecosystem. This effects the fertilization of surface waters and upsets the balance in the ecosystem. The increase in nutrients can lead "...to the proliferation of aquatic photosynthetic plant life..." which may lead to foul odours of the water body or to the death of the fish populations. (Athena)

The ozone depletion potential is a measure of a substance's potential to reduce the protective ozone layer. This can be caused by ozone depleting substances such as CFCs, HFCs, and halons. The impact indicator is reported as CFC-11 equivalence. (Athena)

The smog potential quantifies the air emissions from industry and transportation that are trapped close to the earth's surface. Ozone is a product of the interactions of the volatile organic compounds (VOCs) and nitrogen oxides (NO_X). This indicator is expressed as an equivalent mass of ethylene. (Athena)

Sources of Uncertainty

The time and space uncertainty was one of the largest uncertainties facing the Hennings Building analysis. The assumption was made that the building was being designed to be built today; however, at the same time, the building materials and methods have changed drastically in the last 50 years. The LCA program used modern impact values. Nonetheless, the analysis was beneficial in looking at how the construction industry has changed over the years.

The spatial uncertainty with this analysis stems from the fact that not all the emissions occurred in the same place. The manufacturing emissions occurred at their designated production plants and the transportation emissions occurred over the distance from the plant and the building site. Also the different emissions have their different travel potential. The emissions released into the air generally have a greater travel potential than emissions into the water. The emissions into earth generally have the shortest travel path. However, it depends on the specific circumstances and here lies the uncertainty of the emission results of the LCA analysis.

The temporal uncertainty is caused by the emission shelf life. Different emissions last different amounts of time and this is not accounted for in the LCA outputs.

The LCA emission results do not account for any emission interactions. In actuality, the emissions could react with each other to create new emissions that the model does not report.

Sensitivity Analysis

A sensitivity analysis on material quantities is important for understanding the effects different materials have on the overall building impact. This has applications in the building design phase when decisions are made on material strengths and quantities. It can also be applied during the operating phase of the structure. In this case, it would facilitate decision making with regards to the building maintenance schedule and potential building upgrades. Decision makers would have a better understanding of the implications of a percent increase or decrease in material quantities on various summary measures. When conducting the sensitively analysis, it was found that the majority of the summary measure increases were accrued in the manufacturing stage of the given material.

Concrete – 3000psi

A sensitivity analysis was conducted on a 10% increase in the 3000psi concrete used in the majority of the concrete structure. This correlated to an added 433m^3. The largest percent increase was found to be a 6% increase in resource use. These results showed that the percent increase in concrete usage directly correlated with the increase in resources required. The second largest impact was an effect on 5 other summary measures. The added concrete had a similar impact on the primary energy consumption, the global warming potential, the acidification potential, the HH respiratory effects potential, and the smog potential. The addition of concrete to the structure was observed to be sensitive to increases in the summary measures. In considering building maintenance and upgrades, it would be advisable to limit the amount of concrete added to the structure wherever possible.

Green Lumber

Green lumber was used in the building system for wood stud wall assemblies. A 10% increase in green lumber in the structure equates to $13m^3$ of extra basic materials. This was reflected in the summary measures as a 0.1% increase in resource use. The other summary measures only increased by 0.04% at the most and were considered insignificant. An increase in green lumber in the structure would have minimal impact on the environmental impact of the structure.

Standard Glazing

The standard glazing in the Hennings Building was used as the exterior window material. A 10% increase in the standard glazing resulted in a 0.5% increase in HH respiratory effects potential. This is caused by the particulate material that this released during the manufacturing of the extra glass windows. The impact is worth noting, but is not of huge concern as the impact has not increased a significant amount.

Rockwool Insulation

The Rockwool insulation was the thermal barrier used in the exterior walls of the building. By increasing this quantity by 10%, the acidification potential, the HH respiratory effects potential, and the smog potential had the largest percent increases. The increases were 0.3%, 0.4%, and 0.3%, respectively. All increases were noted at the manufacturing stage of the material.

Gypsum Board

A sensitivity analysis was also conducted on the amount of gypsum board used in the building. The ½" gypsum board quantity was increased by 10%. It was observed that this had the largest impact on the primary energy consumption summary measure. This impact increased 0.5% and was largely observed in the material manufacturing and transportation from the manufacturing facility. This shows that the manufacturing and transport of gypsum board in energy intensive and an increase in gypsum material of 10% will correlate to an increased primary energy use of approximately 0.5%. The acidification potential and the HH respiratory effects potential were also affected with a 0.3% increase of each summary measure. These impacts were both accrued in the manufacturing of the gypsum board material.

Building Performance

The Hennings Building was modelled in the Impact Estimator as it was designed in 1945. These building inputs were then upgraded to meet the Residential Environmental Assessment Program's (REAP) insulation requirements. The roof and walls were equipped with extruded polystyrene insulation. The exterior walls were modelled with 4" thick insulation and the roof was modelled with 8" thick insulation. Extruded polystyrene has an R-value of 5.0 per inch and the improved walls have been equipped with 4 inches. The wall insulation is thus R-20. Since insulation is only available in round denominations, the walls have been slightly over insulated to R-20 while REAP only requires R-18.

The building was upgraded to REAP standards to compare the current operating energy of the poorly insulated building to one the in currently observed as an efficiently insulated structure. The residential guide was used since an institutional building environment assessment guide was not available.

Extruded polystyrene was the chosen insulation because of its high R-value of 5.0 (*ColoradoENERGY*, 2004) and for its "…key attributes of a "green" building material, i.e., recycled and/or recovered content; reusability/recyclability; durability, embodied energy, and air quality." (Fabian, 2004).

The windows were modelled as PVC framed, low E silver, argon filled glazing with a ½" airspace. The window frames were updated to the current industry standard of PVC over the original aluminum frame. Also, a low E silver coating and argon filled double glazing was chosen to reduce the heat transfer through the glazing and to reduce the solar heat gain. The silver coating was chosen over the tin coating to show the effects of an optimized structure at today's standards.

The embodied energy of the original Hennings Building was determined based on the structural and envelope materials used in the initial structure. With all the building data in the Impact Estimator which estimated the quantity of embodied energy in the structure as 21,187,000 Mega Joules. The embodied energy in the improved Hennings model was 25,411,000 Mega Joules. The increase in embodied energy was related to the increase in insulating materials added to the building envelope.

To calculate the thermal resistance of the original and improved Hennings Buildings, the exterior areas, including the windows, the walls, and the roof, were measured with the OST software. The R-values for the corresponding building envelope system was also determined based on the building materials used and the insulation provided. The insulation was then upgraded to meet the REAP standards as outlined above. The results can be found in Table 2.

Table 3: Thermal Resistance Values for the Original and Improved Building

		R-Value (ft^2*deg F*hr/BTU)	
	Area (ft2)	'Original' Building	'Improved' Building
Exterior Wall	17300	6.28	20
Window	8800	0.91	3.45
Roof	39500	0.45	40
Weighted Average	65600	2.05	29.30

The operating energy usage per year was calculated according to the heat loss equation (2). The heat loss was calculated on a month by month basis and the sum of these heat losses over the year was equated to the operating energy. To find the differential temperature (ΔT), the interior temperature was set at 68F (20^{o}C) and the historical average for a given month was used as the exterior temperature. The area of external exposure (A) was the summation of the external wall area, the window area, and the roof area. The R-value (R) used was the weighted average of the thermal resistance based on the surface area of the given medium.

Equation 3: Thermal Conductivity = Q = A (ΔT)/R

The embodied energy of the building materials was input at time zero and the annual operating energies were added year by year. By plotting the current energy consumption against the improved energy consumption, one could extrapolate the energy pay-back period based on the intersection of the two functions (Figure X). For the Hennings Building, the pay-back period was roughly 9 months. The added embodied energy in the form of better insulation in the walls and roof, as well as, better insulating windows with a lower heat transfer would lower the operating energy significantly and would pay for itself in less than a year.

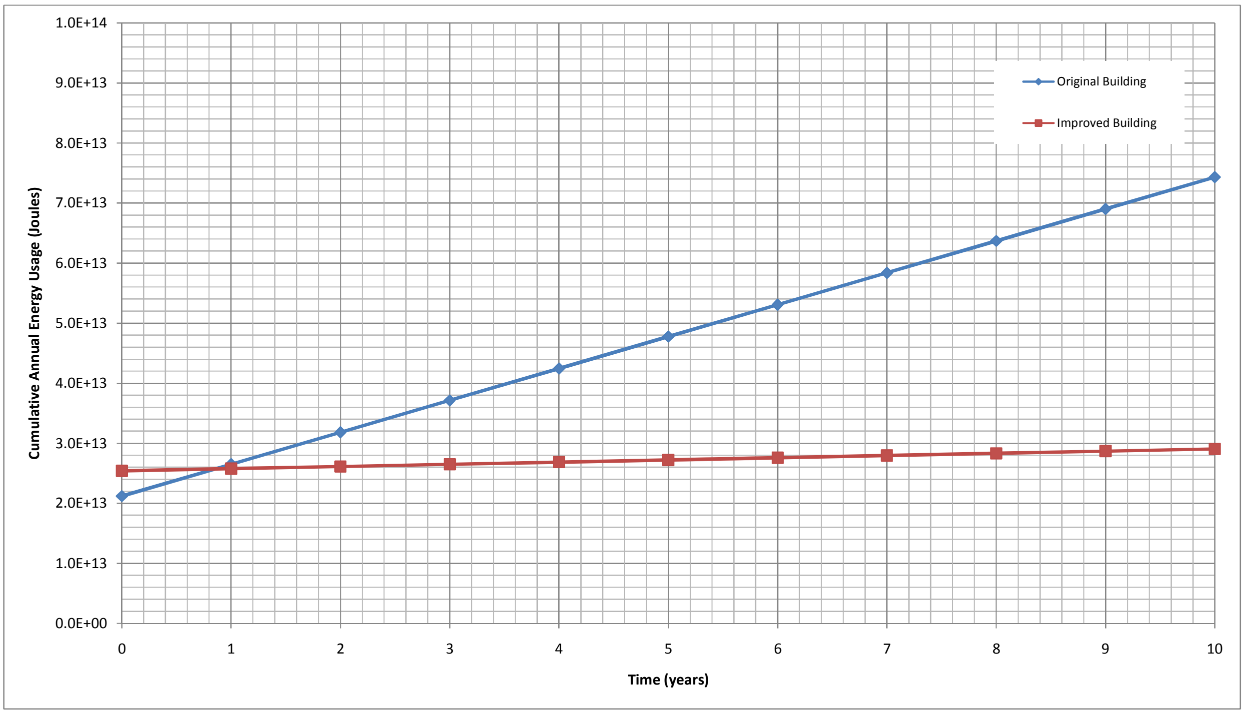

Figure 1: The Hennings Building Cumulative Energy Usage Vs Time

Conclusions

By analysing the Hennings Building from cradle-to-gate, the summary measures were able to quantify the environmental impacts the structure has on the environment. The primary energy required to manufacture the materials and construct the building was a major environmental impact, 163MJ/sqft. Also, the weighted resource use was estimated at 135kg/ sqft as an equivalent weight of fossil fuels. The reinforced concrete used in the majority of the structural system was the most sensitive to environmental impacts with material quantity changes. It would be highly recommended to upgrade the thermal resistance of the structure, as the payback period was found to be less than one year.

References

Hennings Building. (n.d.). Retrieved March 20, 2009, from http://www.library.ubc.ca/archives/bldgs/hennings.html

Hennings Building. (n.d.). Retrieved March 20, 2009, from http://www.maps.ubc.ca/PROD/index_detail.php?show=y,n,n,y,n,y&bldg2Search=n&locat1=652

Lotz, B. (2006, February 1). *A brief history of Thermal Insulation - RSI*. Retrieved March 21, 2009, from http://www.rsimag.com/rsi/Insulation/A-brief-history-of-Thermal-Insulation/ArticleStandard/Article/detail/312975

EPDM - A History of Success. (n.d.). Retrieved March 21, 2009, from http://www.spri.org/media/epdm_roofing.html

EPDM Roofing and EPDM Coatings History with Liquid Roof and Liquid Rubber. (n.d.). Retrieved March 21, 2009, from http://www.epdmcoatings.com/history.html

The History of EPDM and its Reputation. (n.d.). Retrieved March 21, 2009, from http://www.buyliquidroof.com/history.html

EPDM Waterproofing Membrane. (n.d.). Retrieved March 21, 2009, from http://www.procachem.com/Products/Construction%20Chemicals/EEPDM.HTM

Fabian, B., Herrenbruck, S., & Hoffee, A. (2004, April 15). *The Environmental and Societal Value of Extruded Polystyrene Foam Insulation*. Retrieved March 21, 2009, from http://www.xpsa.com/enviro/PDFs/Fabian_Hoffee_Herrenbruck_Earthtech_2004.pdf

ColoradoENERGY.org - R-Value Table . (2004, April 15). Retrieved March 21, 2009, from http://www.coloradoenergy.org/procorner/stuff/r-values.htm

Appendix A: Impact Estimator Input Tables

General Description				
	Project Name		Hennings Building	
	Project Location		Vancouver	
	Building Life Expectancy (Years)		1	
	Building Type		Institutional	
	Operating Energy Consumption (kWh)		803435.25	
Assembly Group	**Assembly Type**	**Assembly Name**	**Input Fields**	**Input Values**
				Known/Measured
1 Foundation				
	1.1 Concrete Slab on Grade			
		1.1.1 - Basement Slab		
			Length (ft)	271.5
			Width (ft)	145.5
			Thickness (in)	4
			Concrete (psi)	3000
			Concrete Flyash %	average
		1.1.2 - East Stairway Slab		
			Length (ft)	71.5
			Width (ft)	5.5
			Thickness (in)	4

			Concrete (psi)	3000
			Concrete Flyash %	average
		1.1.3 - West Stairway Slab		
			Length (ft)	71.5
			Width (ft)	5.5
			Thickness (in)	4
			Concrete (psi)	3000
			Concrete Flyash %	average
		1.1.4 - Main Stairway Slab		
			Length (ft)	48
			Width (ft)	6.5
			Thickness (in)	4
			Concrete (psi)	3000
			Concrete Flyash %	average
	1.2 Concrete Footing			
		1.2.1 - 10" exterior wall - basement		
			Length (ft)	553
			Width (ft)	1.17
			Thickness (in)	10
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.2 - 10" exterior wall - basement		
			Length (ft)	427
			Width (ft)	2
			Thickness (in)	10

			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.3 - 8" exterior wall - basement		
			Length (ft)	46
			Width (ft)	1
			Thickness (in)	10
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.4 - 8" interior wall - basement		
			Length (ft)	798
			Width (ft)	1
			Thickness (in)	10
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.5 - 10" interior wall - basement		
			Length (ft)	65
			Width (ft)	1.17
			Thickness (in)	10
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.6 - 6" interior wall - basement		

			Length (ft)	17
			Width (ft)	1
			Thickness (in)	10
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.7 - 8" interior wall - basement		
			Length (ft)	28
			Width (ft)	1.17
			Thickness (in)	10
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	5
		1.2.8 - 3' column foundation		
			Length (ft)	7.5
			Width (ft)	2.5
			Thickness (in)	16
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	6
		1.2.9 - 4' column foundation		
			Length (ft)	20
			Width (ft)	4
			Thickness (in)	18
			Concrete (psi)	3000
			Concrete Flyash %	average
			Rebar	6

		1.2.10 - 5' column foundation			
			Length (ft)	310	
			Width (ft)	5	
			Thickness (in)	12	
			Concrete (psi)	3000	
			Concrete Flyash %	average	
			Rebar	6	
		1.2.11 - 6' column foundation			
			Length (ft)	96	
			Width (ft)	6	
			Thickness (in)	13.5	
			Concrete (psi)	3000	
			Concrete Flyash %	average	
			Rebar	6	
		1.2.12 - 8' column foundation			
			Length (ft)	64	
			Width (ft)	8	
			Thickness (in)	16.5	
			Concrete (psi)	3000	
			Concrete Flyash %	average	
			Rebar	6	
2 Walls					Known/Measured (Metric)
	2.1 Cast-in-Place				
		2.1.1 - 10" Exterior Wall - basement			
			Length (ft)	461	140
			Height (ft)	12.5	3.81
			Thickness (in)	12	300

			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Window Opening	Number of Windows	9	9
			Total Window Area (ft2)	125	11.6
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard
		Door Opening	Number of Doors	4	4
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.2 - 10" Exterior Wall Front - basement			
			Length (ft)	356	108
			Height (ft)	12.5	3.81
			Thickness (in)	12	300
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Window Opening	Number of Windows	20	20
			Total Window Area (ft2)	254	23.6
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard

		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.3 - 8" Exterior Wall - basement			
			Length (ft)	46	14.0
			Height (ft)	12.5	3.81
			Thickness (in)	8	200
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.4 - 8" Interior Wall - basement			
			Length (ft)	798	243.2
			Height (ft)	12.5	3.81
			Thickness (in)	8	200
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15

		Door Opening	Number of Doors	6	6
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.1.5 - 10" Interior Wall - basement			
			Length (ft)	54	16.5
			Height (ft)	12.5	3.81
			Thickness (in)	12	300
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Door Opening	Number of Doors	1	1
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.1.6 - 6" Interior Wall - basement			
			Length (ft)	12.8	3.9
			Height (ft)	12.5	3.81

			Thickness (in)	8	200
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.1.7 - 8" Interior Wall (elevator) basement			
			Length (ft)	28	8.5
			Height (ft)	12.5	3.81
			Thickness (in)	8	200
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.1.8 - Concrete Interior Wall - 1st Floor			
			Length (ft)	179	54.6
			Height (ft)	12.5	3.81

			Thickness (in)	8	200
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.1.9 - 10" Exterior Wall - 1st Floor			
			Length (ft)	736	224
			Height (ft)	12.5	3.81
			Thickness (in)	12	300
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Window Opening	Number of Windows	228	228
			Total Window Area (ft2)	4308	400
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard
		Door Opening	Number of Doors	12	12
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-

			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.91 - 10" Exterior Wall - 1st Floor			
			Length (ft)	736	224
			Height (ft)	12.5	3.81
			Thickness (in)	12	300
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Window Opening	Number of Windows	228	228
			Total Window Area (ft2)	4308	400
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard
		Door Opening	Number of Doors	12	12
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.92 - 10" Exterior Wall - 1st Floor			
			Length (ft)	736	224
			Height (ft)	12.5	3.81
			Thickness (in)	12	300

			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Window Opening	Number of Windows	228	228
			Total Window Area (ft2)	4308	400
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard
		Door Opening	Number of Doors	12	12
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.10 - Concrete Interior Wall - 2nd Floor			
			Length (ft)	169	51.5
			Height (ft)	12.5	3.81
			Thickness (in)	8	200
			Concrete (psi)	3000	20.684271
			Concrete Flyash %	average	average
			Rebar	5	15
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board

			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.1.11 - Exterior Wall - 2nd Floor			
			Length (ft)	1061	323
			Height (ft)	12.5	3.81
			Thickness (in)	12	300
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15
		Window Opening	Number of Windows	198	198
			Total Window Area (ft2)	4118	382.6
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.111 - Exterior Wall - 2nd Floor			
			Length (ft)	1061	323
			Height (ft)	12.5	3.81
			Thickness (in)	12	300
			Concrete (psi)	3000	20
			Concrete Flyash %	average	average
			Rebar	5	15

		Window Opening	Number of Windows	198	198
			Total Window Area (ft2)	4118	382.6
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
	2.2 Curtain Walls				
		2.2.1 - Glass Interior Wall - 1st Floor			
			Length (ft)	167	50.9
			Height (ft)	12.5	3.81
			Percent Viewable Glazing (%)	70	70
			Percent Spandrel Panel (%)	30	30
			Thickness of Insulation (in)	4	100
			Metal/Opaque Glass	metal	metal
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.2.2 - Glass Interior Wall - 2nd Floor			
			Length (ft)	283	86
			Height (ft)	12.5	3.81
			Percent Viewable Glazing (%)	70	70
			Percent Spandrel Panel (%)	30	30

			Thickness of Insulation (in)	4	100
			Metal/Opaque Glass	metal	metal
		Door Opening	Number of Doors	14	14
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Envelope Category	Gypsum board	Gypsum board
			Envelope Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
	2.3 Wood Stud				
		2.3.1 - Architectural Basement Walls			
			Wall Type	Interior	Interior
			Length (ft)	1637	499
			Height (ft)	12.5	3.81
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Door Opening	Number of Doors	40	40
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		Envelope	Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.3.2 - Interior Wall - 1st Floor			
			Wall Type	Interior	Interior

			Length (ft)	2447	746
			Height (ft)	12.5	3.81
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Door Opening	Number of Doors	63	63
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.3.3 - Interior Wall - 2nd Floor			
			Wall Type	Interior	Interior
			Length (ft)	2395	730
			Height (ft)	12.5	3.81
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Door Opening	Number of Doors	56	56
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-

			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
		2.3.4 - Exterior Wall Extra			
			Wall Type	Exterior	Exterior
			Length (ft)	502	153
			Height (ft)	12.5	3.81
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Envelope Category	Insulation	Insulation
			Envelope Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.3.5 - Exterior Wall Around Light Well			
			Wall Type	Exterior	Exterior
			Length (ft)	390	119
			Height (ft)	12.5	3.81
			Sheathing	none	none
			Stud Thickness	6	150
			Stud Spacing	16	400
			Stud Type	Green	Green
		Window Opening	Number of Windows	52	52
			Total Window Area (ft2)	1081	100
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard	Standard

		Envelope	Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
			Thickness	-	-
			Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness (in)	2	-
		2.1.1a - 2x4 Wood Frame Wall			
		Envelope	Wall Type	Exterior	Exterior
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
			Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.2a - 2x4 Wood Frame Wall			
		Envelope	Wall Type	Exterior	Exterior
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
			Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.3a - 2x4 Wood Frame Wall			
			Wall Type	Exterior	Exterior
			Sheathing	none	none

			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.9a - 2x4 Wood Frame Wall			
			Wall Type	Exterior	Exterior
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.91a - 2x4 Wood Frame Wall			
			Wall Type	Exterior	Exterior
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.92a - 2x4 Wood Frame Wall			
			Wall Type	Exterior	Exterior

			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.11a - 2x4 Wood Frame Wall			
			Wall Type	Exterior	Exterior
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
		2.1.111a - 2x4 Wood Frame Wall			
			Wall Type	Exterior	Exterior
			Sheathing	none	none
			Stud Thickness	4	100
			Stud Spacing	16	400
			Stud Type	Green	Green
		Envelope	Category	Insulation	Insulation
			Material	Rockwool	Rockwool
			Thickness	2	-
3 Mixed Columns and Beams					

	3.1 Concrete Column and Concrete Beam			
		3.1.1 - Basement Beams and Columns		
			Number of Beams	80
			Number of Columns	118
			Floor to Floor Height (ft)	12.5
			Bay Sizes (ft)	13.5
			Supported Span	14.5
			Live Load (psf)	100
		3.1.2 - 1st Floor Beams and Columns		
			Number of Beams	80
			Number of Columns	118
			Floor to Floor Height (ft)	12.5
			Bay Sizes (ft)	13.5
			Supported Span	14.5
			Live Load (psf)	60
		3.1.3 - 2nd Floor Beams and Columns		
			Number of Beams	80
			Number of Columns	118
			Floor to Floor Height (ft)	12.5
			Bay Sizes (ft)	13.5
			Supported Span	14.5
			Live Load (psf)	40
4 Roofs				

	4.1 Concrete Precast Double T			
		4.1.1 - Roof		
			Number of Bays	66
			Bay Sizes (ft)	20
			Span (ft)	30
			Live Load (psf)	40
			Topping	yes
5 Floors				
	5.1 Suspended Slab			
		5.1.1 - 1st Floor		
			Floor Width (ft)	1316.8
			Span (ft)	30.0
			Concrete (psi)	3000
			Concrete Flyash %	average
			Live Load (psf)	100
		5.1.2 - 2nd Floor		
			Floor Width (ft)	1138.0
			Span (ft)	30.0
			Concrete (psi)	3000
			Concrete Flyash %	average
			Live Load (psf)	60

Appendix B: Impact Estimator Input Assumptions Document

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Add Foundation	The Concrete Slab on Grade (SOG) was accounted for using the length and width of the basement slab. Since takeoffs for SOGs require a length, width and thickness measurements, these inputs were obtainable without the creation of takeoff conditions. In the Impact Estimator, the SOG inputs are limited to being either a 4" or 8" thickness. The SOG thickness was 4" (652-07-005). The length and width of the slab was also read off the drawing. Concrete footings were modeled using a combination of linear and count condition types depending on the type of footing being measured. For instance, strip footings were measured using linear conditions. Since the basement plan (652-07-005) stated the width and thickness measurements for the different strip footing types, only the length of the footings was required by a linear condition. Column footings were accounted for using count conditions since their length, width and thicknesses were provided in the basement structural drawing (652-07-005). The Impact Estimator limits the thickness of footings. In this case, footings thicknesses are limited to a maximum of 19.7" thick. As there are a number of cases where footing thicknesses exceed 19", their thickness was divided by two and their length was doubled. This maintained the concrete volume and provided an input within the limitations. Lastly, a linear condition was used to model the concrete stairs as footings (652-07-016 and 652-07-017). After measuring an average thickness and width, the length of stairs was measured using a linear condition.		
	1.1 Concrete Slab-on-Grade		
		1.1.1 - Basement Slab	Refer to general foundation notes above
		1.1.2 - East Stairway Slab	Refer to general foundation notes above
		1.1.3 - West Stairway Slab	Refer to general foundation notes above
		1.1.4 - Main Stairway Slab	Refer to general foundation notes above
	1.2 Concrete Footing		
		1.2.1 - 10" exterior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12
		1.2.2 - 10" exterior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12
		1.2.3 - 8" exterior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12

		1.2.4 - 8" interior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12
		1.2.5 - 10" interior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12
		1.2.6 - 6" interior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12
		1.2.7 - 8" interior wall - basement	The width of this slab was given in inches and was converted to feet. Thickness was less than 19", no modification required. (width in feet) = (width in inches)/12
		1.2.8 - 3' column foundation	The column foundations were input as continous strip foundations. The columns were counted using the count condition. Thickness was less than 19", no modification required. Volume = Width * (Width*count) * Depth
		1.2.9 - 4' column foundation	The column foundations were input as continous strip foundations. The columns were counted using the count condition. Thickness was less than 19", no modification required. Volume = Width * (Width*count) * Depth
		1.2.10 - 5' column foundation	The column foundations were input as continous strip foundations. The columns were counted using the count condition. Thickness was greater than 19", modification required. Limitation avoided as follows: Volume = Width * (Width*count*2) * Depth/2
		1.2.11 - 6' column foundation	The column foundations were input as continous strip foundations. The columns were counted using the count condition. Thickness was greater than 19", modification required. Limitation avoided as follows: Volume = Width * (Width*count*2) * Depth/2
		1.2.12 - 8' column foundation	The column foundations were input as continous strip foundations. The columns were counted using the count condition. Thickness was greater than 19", modification required. Limitation avoided as follows: Volume = Width * (Width*count*2) * Depth/2

2 Add Walls	In modeling the respective wall types, linear conditions were used to measure their lengths. Separate count conditions were utilized to account for window and door openings within each respective wall type. Area conditions were utilized to calculate the glazing area for the exterior walls. Envelope and opening details were sourced from building inspections and documents related to building material history. Several assumptions were made in order to complete modeling of the walls. The length of the concrete cast-in-place walls were modified to accommodate the wall thickness limitations in the IE. The interior partition walls were assumed to be 2x4 wood stud walls. No sheathing was used as lateral stability was assumed to be achieved by the concrete structure. The exterior cast-in-place walls were modelled with a 2x4 wood stud walls on the interior to house the Rockwool insulation. By visual inspection, the windows were assumed to be aluminum frame with standard glazing and the doors were assumed to be solid wood. The window areas were calculated using area conditions on the elevation drawing (652-06-058). The interior walls were modelled with gypsum board on both sides and the exterior walls had gypsum on the interior side only. The lumber used in the wood stud walls was assumed to be green as was common practice at time of construction.All wall inputs were done in SI because of a conversion issue with the IE.		
	2.1 Cast In Place		
		2.1.1 - 10" Exterior Wall - basement	This wall length was reduced by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; Input Length = (Measured Length) * [(Cited Thickness)/12”] This wall was modelled with a 2x4 wood stud wall adjacent to it (2.1.1a). This simplified the model by only inputting the window and door openings once. The volume consideration above affected the input length. An extra exterior wood stud wall input was required to make up for the added length of the wall (2.3.4).
		2.1.2 - 10" Exterior Wall Front - basement	This wall length was reduced by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; Input Length = (Measured Length) * [(Cited Thickness)/12”] This wall was modelled with a 2x4 wood stud wall adjacent to it (2.1.2a). This simplified the model by only inputting the window and door openings once. The volume consideration above affected the input length. An extra exterior wood stud wall input was required to make up for the added length of the wall (2.3.4).
		2.1.3 - 8" Exterior Wall - basement	Refer to general wall notes above
		2.1.4 - 8" Interior Wall - basement	Refer to general wall notes above
		2.1.5 - 10" Interior Wall - basement	This wall length was reduced by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; Input Length = (Measured Length) * [(Cited Thickness)/12”]

		2.1.6 - 6" Interior Wall - basement	This wall length was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; Input Length = (Measured Length) * [(Cited Thickness)/8”]
		2.1.7 - 8" Interior Wall (elevator) basement	Refer to general wall notes above
		2.1.8 - Concrete Interior Wall - 1st Floor	Refer to general wall notes above
		2.1.9 - 10" Exterior Wall - 1st Floor	This wall length was reduced by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; Input Length = (Measured Length) * [(Cited Thickness)/12”] This wall was modelled with a 2x4 wood stud wall adjacent to it (2.1.9a). This simplified the model by only inputting the window and door openings once. The volume consideration above affected the input length. An extra exterior wood stud wall input was required to make up for the added length of the wall (2.3.4). This wall contained more windows than the IE maximum input (100). To overcome this constraint, the wall was split up into 3 inputs (2.1.9, 2.1.91, and 2.1.92).
		2.1.91 - 10" Exterior Wall - 1st Floor	Refer to 2.1.9
		2.1.92 - 10" Exterior Wall - 1st Floor	Refer to 2.1.9
		2.1.10 - Concrete Interior Wall - 2nd Floor	Refer to general wall notes above
		2.1.11 - Exterior Wall - 2nd Floor	This wall length was reduced by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; Input Length = (Measured Length) * [(Cited Thickness)/12”] This wall was modelled with a 2x4 wood stud wall adjacent to it (2.1.11a). This simplified the model by only inputting the window and door openings once. The volume consideration above affected the input length. An extra exterior wood stud wall input was required to make up for the added length of the wall (2.3.4). This wall contained more windows than the IE maximum input (100). To overcome this constraint, the wall was split up into 2 inputs (2.1.11 and 2.1.111).

		2.1.111 - Exterior Wall - 2nd Floor	Refer to 2.1.11
	2.2 Curtain Wall		
		2.2.1 - Glass Interior Wall - 1st Floor	Assumed to be 70% glazing, 30% spandrel
		2.2.2 - Glass Interior Wall - 2nd Floor	Assumed to be 70% glazing, 30% spandrel
	2.3 Wood Stud		
		2.3.1 - Architectural Basement Walls	Refer to general wall notes above
		2.3.2 - Interior Wall - 1st Floor	Refer to general wall notes above
		2.3.3 - Interior Wall - 2nd Floor	Refer to general wall notes above
		2.3.4 - Exterior Wall Extra	Additional exterior wall to accommodate the shortened cast-in-place walls as noted for 2.1.1, 2.1.2, 2.1.9, and 2.1.11.
		2.3.5 - Exterior Wall Around Light Well	Modelled as 2x6 exterior wall with 2 inches of Rockwool insulation. Lightwell detail shown on 2nd floor architectural plan (652-06-067).
		2.1.1a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.1. Contains 2 inches Rockwool insulation.
		2.1.2a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.2. Contains 2 inches Rockwool insulation.
		2.1.3a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.3. Contains 2 inches Rockwool insulation.
		2.1.9a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.9. Contains 2 inches Rockwool insulation.
		2.1.91a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.91. Contains 2 inches Rockwool insulation.
		2.1.92a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.92. Contains 2 inches Rockwool insulation.
		2.1.11a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.11. Contains 2 inches Rockwool insulation.
		2.1.111a - 2x4 Wood Frame Wall	Insulating wall adjacent to 2.1.111. Contains 2 inches Rockwool insulation.
3 Mixed Columns and Beams	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. The concrete columns were accounted for on each floor by reading the column number on the NW corner of the building as indicated by the structural designer. The number of beams supporting each floor were assigned an average bay and span size in order to cover the measured area. Since the design live load on the 1st floor was 60psf, a live load of 75psf was assumed. Also the design live load on the 2nd floor was 40psf, so a live load of 45psf was assumed.		
	3.1 Concrete Column and Concrete Beam		
		3.1.1 - Basement Beams and	Refer to general beam and column notes above

		Columns	
		3.1.2 - 1st Floor Beams and Columns	Refer to general beam and column notes above
		3.1.3 - 2nd Floor Beams and Columns	Refer to general beam and column notes above
4 Add Roof	The roof was modeled using an area condition. The live load was designed to be 40 psf and was modelled as 45psf. The number of bays was calculated by dividing the roof area by the span size and the bay size.		
	4.1 Concrete Precast Double T		
		4.1.1 - Roof	Refer to general roof notes above
5 Add Floors	For the floor inputs, much like in column and beams, the Impact Estimator calculated the thickness of the material based on some basic variables regarding the assembly. These include; floor width, span, concrete strength, concrete flyash content and live load. The floor area was calculated using the stated length and width of the building. The 2nd floor area was equal to the gross floor area minus the area of the light well. The maximum span allowed in the IE is 30ft. The floor width was calculated by dividing the floor area by the 30ft span. The live load on the roof was designed at 40psf.		
	5.1 Suspended Slab		
		5.1.1 - 1st Floor	Refer to general floor notes above
		5.1.2 - 2nd Floor	Refer to general floor notes above