CIVL 498C

Life Cycle Analysis of Fairview Crescent Student Housing – UBC Campus Vancouver

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Abstract

This analysis of the Fairview Crescent Student Housing Development used OnScreen Takeoff Software to create a material list for the development. This material list, supplemented with specific assembly details obtained from architectural and structural drawings, was inputted into Athena Institute's Impact Estimator Software. The Impact Estimator uses the TRACI impact database to quantify the environmental impacts of the building assemblies.

The outputs from the Impact Estimator include a Bill of Materials and summary measures by life cycle stage and assembly group. The information obtained in this analysis will be used in conjunction with the information created from the additional reports produced in CIVL 498C to analyze the potential environmental impacts of different building types on campus. The summary measures by life cycle stage showed the majority of the environmental impacts are associated with the manufacturing stage of the building. In addition, the assembly group with the largest primary energy usage is the roof assembly. This is most likely due to the significant amount of asphalt shingles and fibreglass batt insulation incorporated in this assembly.

A sensitivity analysis was undertaken on the 5 most prevalent materials to investigate the relative impacts each material has on the development's overall environmental impact. It was determined that the most influential component out of the five chosen was the interior gypsum board. This is due in part to the significant amount incorporated in the development and the large primary energy needed in the manufacturing stage as well as the significant acidification, HH potential, weighted resource use and global warming potential effects.

In addition, an analysis was undertaken to determine the amount and cost of materials needed to improve the current buildings energy performance to UBC's current building energy standards, REAP. Operating energy data was obtained from the UBC building services department and a spreadsheet template was used to determine the improvement of operating energy given material upgrades. It was determined that the addition of 1" extruded polystyrene to the exterior walls and an additional 3.5" of R-10 fibreglass batt in the roof assembly could improve the energy performance to REAP standard. An estimate of the additional materials based on retail material costs is $87 000. It was also found the higher initial investment in material energy (ie. embodied energy) would pay for itself in approximately 43 months.

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Introduction

This report summarizes a life cycle analysis (LCA) of the UBC Vancouver student housing development: Fairview Crescent, undertaken for the course CIVL 498C. Fairview Crescent Student Housing was built in 1985 by Waisman, Dewar, Grout Architects and Planners for the Acadia Student Housing Department of UBC.

The development plan incorporates three distinctive building layouts arranged on either side of pedestrian only brick streets. The three different building plans are denoted by the letters A, B and C (see Figure 1: Community Plan). The building layouts vary in size from approximately 4500 to over 7300 sq.ft.. This translates into a total of 186 four, five and six bedroom townhouses as well as three laundry facilities and a community coffee shop.

The buildings are all 3 story wood frame with concrete basements. 180 parking spots are also available for students in an underground parking garage located under blocks Z and U (see Figure 2: Block Key Plan). The parking spots are allocated every year using a lottery system. Table 1 lists additional building characteristics in detail.

Table 1: Fairview Crescent Building Characteristics

Building System	Specific Characteristics of Fairview Crescent
Structure	Light Wood Frame
Floors	1/2 of the units slab on grade - 6" thick, 1/2 of the units on top of below ground concrete parking garage - 8" thick slab and walls. 2nd and 3rd Floor: TJI floor joists, 3/4" plywood (2nd Floor 1 1/2" lightweight concrete topping)
Exterior Walls	**Basement Parking Garage**: Cast in place walls; **Ground**: modular brick cladding, 1/2" regular gypsum interior, 1" expanded polystyrene, 3" polystyrene, 3 mil vapour barrier; **Second and Third Floors**: 1/2" regular gypsum, 1/2" exterior gypsum or wood bevel siding - pine, 1" expanded polystyrene, 3" fibreglass batt, 3 mil vapour barrier
Interior Walls	2x4 wood studs @ 16" o.c., gypsum sheathing
Windows	All windows aluminum frame and standard glazing
Roof	Main Roof: wood truss, 6" fibreglass batt, asphalt shingles, 6 mil vapour barrier, plywood sheathing.
HVAC	Steam from Central Power Plant, a natural gas fired boiler located on UBC campus

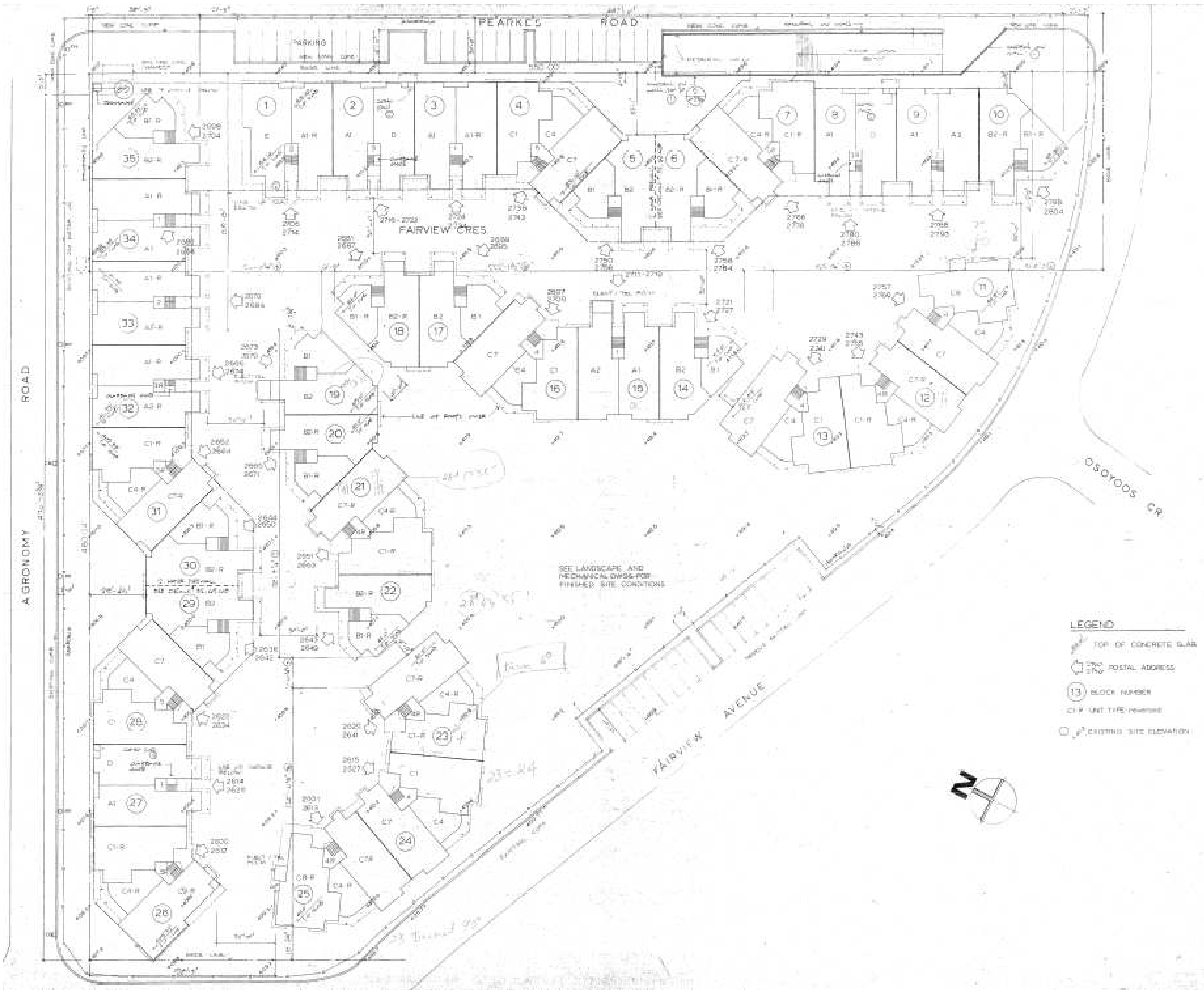

Figure 1: Community Plan

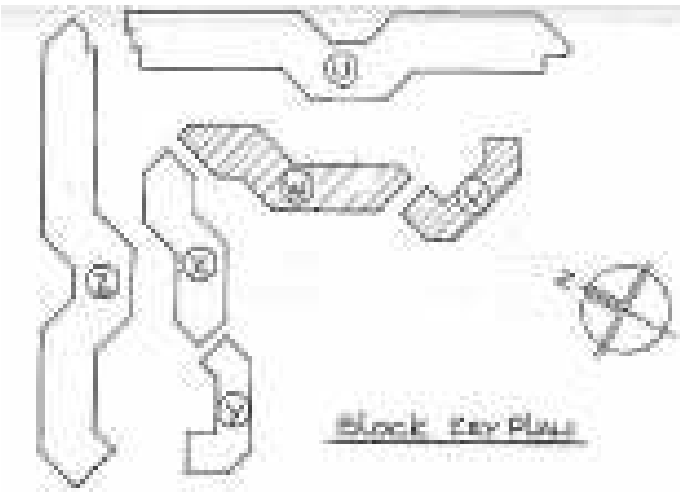

Figure 2: Block Key Plan

This analysis also investigates the environmental impacts of the entire building material list as well as a sensitivity analysis focusing on the 5 main influencing components to see their relative impacts on the environmental performance of the building. This data can be found in the Summary Measures section.

In addition, an analysis using energy consumption data, obtained from UBC utilities, was completed to model the theoretical benefits of building system upgrades. In particular, the analysis investigated the amount of interior insulation necessary to bring the buildings up to current REAP building standards. A short discussion regarding upgrade feasibility and potential issues is also included. This material can be found in the Building Performance section.

Goal of Study

This LCA of FCSHD 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 FCSHD 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 FCSHD. An exemplary application of these references is in the assessment of potential future performance upgrades to the structure and envelope of the FCSHD. 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 FCSHD LCA can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future UBC construction, renovation and demolition projects.

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

Scope of Study

The product systems being studied in this LCA are the structure, envelope and operational energy usage associated with space conditioning of the Fairview Crescent Student Housing Development (FCSHD) on a square foot finished floor area of residential 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 FCSHD, as well as associated transportation effects throughout.

Tools, Methodology and Data

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

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

Using the formatted takeoff data, version 4.0.51 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 FCSHD in the Vancouver region as a multi-unit residential rental 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 FCSHD 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 FCSHD, all of the available TRACI impact assessment categories available in the IE are included in this study, and are listed as;

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

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

The primary sources of data for this LCA are the original architectural and structural drawings from when the FCSHD was initially constructed in 1985. The assemblies of the building that are modeled include the foundation, floors, walls (interior and exterior) and roofs, as well as the associated envelope and openings (ie. 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 Bill of Materials and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further in the Building Model section and, as previously mentioned, all specific input related assumptions are contained in the Input Assumptions document in Annex B.

Building Model

Takeoffs

The takeoff process was completed using On-Screen Takeoff Software. Digital images of the architectural and structural building drawings were obtained through the UBC campus planning and development office. Many details of the interior and exterior walls were not specified within the architectural or structural drawings and these had to be assumed by researching standard residential wood frame housing procedures. A detailed analysis of procedures and assumptions used for the takeoffs follows.

2 Walls

2.1 Exterior Light Wood Frame

The exterior walls are all load bearing and consist of 2x4" wood framing. The exterior systems vary between floors, with the ground floor facade consisting of modular brick and the upper floors consisting of either architectural wood facade or ½" gypsum board. All exterior wall systems have the same basic components, only the facade is different. The wall systems contain:

- 2x4" studs at 16"o.c.
- 1" exterior insulation system (assumed and modeled as expanded polystyrene)
- R10 batt insulation (equivalent to and modeled as 3" fibreglass batt insulation)
- 4 mil vapour barrier (modeled as 3 mil, closest input to the IE)
- ½" interior drywall
- Plywood sheathing (assumed: thickness or material type of sheathing not specified in drawings. As well, the IE does not require an input for plywood sheathing thickness.)

The exterior facades are as follows:

- Wood bevel siding – pine (specific type not specified in drawings but assumed based on research on visual characteristics)
- ½" exterior gypsum board – specified

- brick (modular-metric) - specified

Second and third floor exterior wall information regarding usage of facade materials was not contained in the takeoffs. A site investigation was completed to determine which units were faced with wood facade and which were faced with gypsum wall systems.

The different options for exterior wood siding consisted of:

- Wood bevel siding – cedar, pine or spruce
- Wood shiplap siding – cedar, pine or spruce
- Wood tongue and groove siding – cedar, pine or spruce

An internet search investigating the different facades resulted in the choice of wood bevel siding – pine based on appearance. Pine as the choice of wood is strictly assumed as SPF (spruce, pine, fir) is a common, economical choice for wood framing.

Brick (modular-metric) is a standard brick facade used for most building types. From the list of options available for brick facade in the IE, modular-metric was the most applicable.

Exterior Doors – The type of exterior door were not specified so upon site inspection, steel exterior 50% glazing was decided upon.

2.2 Interior Light Wood Frame

The interior walls consist of load bearing, false and dividing walls. The interior load and false walls were all assumed to be 2x4" construction with studs 16 o.c. and ½" regular gypsum sheathing on both sides of the wall. The load bearing and false walls were all assumed to have the same construction techniques to ease takeoffs because architectural drawings were used to complete the interior wall takeoffs. A slight overestimation of interior wall studs may result but is not expected to significantly skew the results of the analysis. This is the majority of interior walls are load bearing and the difference in materials is slight as false walls are framed at 24" o.c. as opposed to 16" o.c..

The dividing wall materials were calculated using Extra Basic Materials of the IE because of the unique framing attributes of the walls and the large total length (4415 ft). The walls are framed on a double 2x6 base board and header with 2x4 studs in T configurations spaced every 24" on center. The sheathing material is assumed to be standard ½" regular gypsum, which is typical in house framing. The ½" regular gypsum is also included in additional materials (total area = 77700 sqft). Wall heights vary slightly between units and floors, so a standard height of 8'8" is used in the calculations.

Interior Doors were not specified and inputted into the IE as hollow core wood interior.

3 Roofs

3.1 Wood Truss

The roofing system used in the development is wood frame truss. Two separate inputs for each unit were used to account for the main roof spans and the smaller overhangs found on the exterior walls of units. Again, the roof spans were averaged in a similar fashion to the floor spans. Some units had triangular sections and an average of the truss spans was calculated and used as the general input to the IE.

The roof system consists of trusses spanning 48' on average, ½" plywood sheets sheathing the trusses and asphalt shingles overlain on the plywood as the exterior roofing material. The specified thickness for roof sheathing is 3/8" but the closest input to the IE is ½". The drawings specify that the attics are insulated with R20 fibreglass batt insulation which corresponds to 6" fibreglass batt insulation in the IE model. In addition, 6 mil plastic sheeting is used as a vapour barrier. The roof inputs also include ½" regular gypsum which is used to sheath the ceiling of the 3rd floor ceilings.

The smaller roof overhangs are wood frame construction with similar materials used as the roof. The overhangs were calculated on a whole building scale instead of a per floor basis given the ease of input and the fact that the overhangs were uniform in construction and easily replicable over the different floors. The materials used in the overhang construction consist of specified ½" plywood decking, asphalt shingles, ½" gypsum board, 6 mil poly and 6" fibreglass batt insulation.

4 Floors

4.1 Wood I-Joist

The spans for each unit were obtained by dimensioning the average spans for each unit using On-Screen dimensioning tool. For units, such as the B-units, which have irregular spans (because units are triangular in shape), the average of the spans was calculated and divided into the gross floor area to create the span and floor width inputs for the IE.

Decking Thickness and live loads were specified on the structural framing plan drawings. The specified live loads were 40 and 70 psi for the 3rd and 2nd floors respectively. The closest inputs the IE would allow are 45 and 75 psi, which was used to model the floors. The decking thickness was specified as 3/4" plywood throughout with a lightweight concrete topping 1 ½" thick on all 2nd floors.

I-joist dimensions were dimensioned using On-Screen software and the materials used for the flange and web were assumed as MSR and plywood respectively. The maximum span ranges allowable for I-joists within the IE are:

- 11.8 ft - 40 ft for 45 psf loads
- 10.0 ft – 32 ft for 75 psf loads
- 11.8 ft – 23 ft for 100 psf loads

All the spans used in this analysis fall within the acceptable limits governing the maximum lengths.

Envelope materials used in the floor system were assumed to be ½" regular drywall used to frame the underside of the floor system and to create a ceiling for the lower floor. In addition, the 1 ½" concrete topping for 2nd floors is included in Extra Materials. The ceilings of the 3rd floors are included in the roof input's additional materials. The summary concrete includes floor topping and foundation concrete. A breakdown of each component can be found within the Detail of Extra Materials.

5 Extra Basic Materials

5.1 Wood

- Stairs – Assumed:
  - riser height = 8"
  - tread depth = 9"
  - 2x12" stringer
  - tread thickness = ½"
  - Measured volume of wood per stair based on assumptions above and average stair width then calculated volume of wood

5.2 Concrete

- Footings – Slabs on grade footing thicknesses assumed as 10"x10"

5.4 Steel

- Rebar – Determined amount of reinforcing rebar by modelling equivalent slab on grade in the IE and referencing the amount of steel in area in Bill of Materials .

The parking garage was modeled in the IE's underground parking garage option in the floor and roof assemblies. The roof of the parking garage doubles as the floor slab for blocks Z and U.

Materials which were not included in this model are:

- Flooring materials
- plumbing materials
- electrical materials
- appliances
- roof drainage materials
- brick pavers and landscaping materials
- R14 Spray insulation for slab on grade and parking garage insulation

Service materials like plumbing and electrical as well as appliances and finishes (carpets, paints etc.) and landscaping materials were outside the scope of this project. Other materials like spray insulation may have been within the scope of the project but were not included in the takeoffs. In the case of the spray insulation, the underground parking garage was modeled using the parking garage feature in floors, walls and ceiling. Within the drawings, R14 (urethane foam) was specified for the slab but there is no option within The IE to model this material so it was excluded.

Bill of Material

The first step in creating the Bill of Materials (BoM) was done using the building takeoff software On-Screen. Digital structural and architectural drawings for the Fairview Residence were obtained from the UBC planning office to facilitate the use of a software takeoff program to generate the BoM. On-Screen digital takeoff software allows area, linear and count condition inputs to account for the different materials found in the buildings. For example, a linear condition can be used to determine the length of wall and the characteristics of that wall (interior/exterior, sheathing type, insulation thickness) are detailed in a separate Impact Estimator Input Document, seen in Appendix A. The Impact Estimator Input Document's information is then manually input into the IE to generate the LCA model's profile.

As takeoffs are done manually through the OnScreen software, some operator error is assumed to be present in the final impact assessment. Furthermore, certain details in the building like floor areas needing additional TJI joist reinforcing in the floors was not accounted for in the IE model because the floors were inputted as standard wood joist floors. As such, the IE model uses a standard algorithm based on floor area and span to determine the corresponding standard amount of wood used to create a floor of that size. This shows that a trade off between accuracy and convenience is made when using the digital takeoff and impact assessment software.

Table 2: Bill of Materials

Material	Quantity	Unit
1/2" Moisture Resistant Gypsum Board	1410.5444	m2
1/2" Regular Gypsum Board	134718.1679	m2
3 mil Polyethylene	6878.3577	m2
6 mil Polyethylene	16201.8892	m2
Aluminum	151.7684	Tonnes
Batt. Fibreglass	72451.2045	m2 (25mm)
Cold Rolled Sheet	0.3803	Tonnes
Concrete 20 MPa (flyash av)	3808.9356	m3
Concrete 30 MPa (flyash av)	331.6639	m3
Concrete Blocks	3078.6	Blocks
EPDM membrane	9969.8781	Kg
Expanded Polystyrene	5668.5698	m2 (25mm)
Galvanized Sheet	9.8994	Tonnes
Glazing Panel	2.8806	Tonnes
Joint Compound	127.9338	Tonnes
Large Dimension Softwood Lumber, kiln-dried	504.1616	m3
Metric Modular (Modular) Brick	1976.7406	m2
Mortar	51.9531	m3
Nails	57.6733	Tonnes
Paper Tape	1.4683	Tonnes
Pine Wood Bevel Siding	3485.1598	m2
Rebar, Rod, Light Sections	265.2107	Tonnes
Roofing Asphalt	8454.3624	Kg
Small Dimension Softwood Lumber, Green	874.1573	m3
Small Dimension Softwood Lumber, kiln-dried	182.4404	m3
Softwood Plywood	116441.5289	m2 (9mm)
Solvent Based Alkyd Paint	24.172	L
Standard Glazing	9143.7013	m2
Water Based Latex Paint	1219.3602	L

The 5 largest amounts of materials contained within the Bill of Materials are:

- Concrete, average flyash (151 853 ft^3 – includes both 45 and 75 psi)
- Small dimension softwood lumber (37290 ft^3)
- Softwood plywood – 9 mil thickness, approx. 3/8" (1 246 460 ft^2)
- Fibreglass batt insulation (832 900 ft^2)
- ½" regular gypsum (1 428 693 ft^2)

The assembly contributing most to the Bill of Materials in terms of volume is wood framed walls. All interior and exterior walls are wood framed and contain small dimension softwood lumber to frame the walls, softwood plywood (exterior walls) and ½" regular gypsum (interior walls) to sheath them and fibreglass batt insulation is used throughout the walls and ceiling for insulation. An extensive breakdown of material components used in each wall assembly can be found in the Impact Estimator Input Document (Appendix A). Concrete is prevalent in the BoM because of the concrete parking garage, slab on grade foundations and concrete floor topping on all 2nd floors.

All the interior walls are modelled as load bearing, which might result in a slight over estimation for wood materials. With the drawing used, it was difficult to determine which interior walls were specified as load bearing and which were false. The difference between false and load bearing walls occurs in the designated spacing for vertical 2x4s. In a load bearing wall, 2x4s are spaced at 16" o.c., whereas in a false wall they are spaced at 24" on center. It is assumed that this assumption will not have a significant effect on the results and a sensitivity analysis will be conducted to quantify the impacts of small dimension lumber on the model.

The accuracy of the underground parking lot takeoffs done directly in the IE's given number of parking stalls is unknown. The stated number of stalls in the Fairview drawings states 180 underground parking spots but the corresponding number in the IE to model the same square footage is 47 stalls. The walls of the parking garage were assumed to be a uniform 8'6", whereas the height varies to an unknown degree throughout the parking level. Within the drawings it is stated that the height varies but a detailed analysis is not shown. The height of 8'6" was determined from dimensioning a cross section detail of the parking level floor/roof and slab system.
Of interest in the takeoffs is the wood bevel siding – pine and door assemblies. The wood bevel siding component of the exterior wall assembly accounts for the water based latex paint in the takeoffs. This was determined using reverse engineering by first copying each assembly group into its own IE project and investigating the BoM. Once the wall assembly was determined to contain the paint, the components of the wall assembly were removed one at a time and the BoM was checked to see if the paint was still present. Using the same process, the solvent based alkyd paint was identified as belonging to the door components of the wall assembly.

Summary Measures

The summary measures are a created by multiplying the Bill of Materials determined in the IE by factors drawn from an Athena LCI database. In this case, the TRACI impact assessment methodology is used to determine the impacts of the materials used in the Fairview Residence. Within this case study, all summary measures are presented to allow for the fullest use and interpretation of the information created through this project. The study time is for 1 year with no operating or maintenance inclusions for this analysis. This study is strictly to roughly determine the as-built impacts of the building in the IE. An analysis of operating efficiency and the impacts of material upgrades, like increased insulation or windows with higher thermal capacity will be investigated in the next section, Building Performance.

The summary measures are presented by life cycle stage and assembly group. The life cycle stage includes the five distinct phases of a building's life cycle: manufacturing, construction, maintenance, operation and end of life. Only manufacturing and construction will be addressed in this analysis given the 1 year study period. The assembly groups modeled in the Fairview Residence include: foundations, walls, roofs, floors and extra basic materials. Additional assembly groups available in the IE analysis but not incorporated in the Fairview model are columns and beams. Columns and beams are not included because the buildings are wood framed and the parking garage function includes columns and beams automatically. The foundations assembly is not used because half of the foundations are accounted for in the roof parking garage assembly group. The remaining foundations are slab on grade and incorporated in extra basic materials under concrete and steel for convenience.

The 5 materials chosen for sensitivity analysis and their respective amounts are:

- 9 mil (~3/8") softwood plywood (1 246 460 ft^2)
- ½" regular gypsum board (142 8693 ft^2)
- Softwood lumber (37290 ft^3)
- Asphalt roofing system (8200 kg)
- Fibreglass batt insulation (832 900 ft^2)

On the assembly group level, the wood frame wall assemblies have the most significant impact on the development's environmental footprint. This result is intuitive given the huge volume of materials needed to wood frame roughly 200 000 sqft of living space. Within the wood frame assembly, the graphs show that the most significant source of environmental effects comes from the gypsum component. Since gypsum is used to sheath the both sides of interior walls, the interior side of outside walls as well as ceilings on all three floors it is obvious why there is a significant amount included in the development. Furthermore, the manufacturing of gypsum is a very energy intensive process and results in significant acidification potential, global warming potential and resource use.

Other notable changes observed from the sensitivity analysis are summarized in the table below:

Table 3: Notable Changes in Environmental Releases

	Manufacturing	Construction
Concrete	% change	% change
Weighted Resource Use kg	5.50	1.20
Smog Potential (kg NOx eq / kg)	2.60	0.08
Global Warming Potential (kg CO2 eq / kg)	2.51	0.17
Acidification Potential (moles of H+ eq / kg)	2.03	0.11
Gypsum		
Primary Energy Consumption MJ	12.78	4.97
Weighted Resource Use kg	12.50	4.13
Global Warming Potential (kg CO2 eq / kg)	12.19	0.58
Acidification Potential (moles of H+ eq / kg)	10.51	0.36
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	6.66	0.40
Eutrophication Potential (kg N eq / kg)	1.27	6.01
Ozone Depletion Potential (kg CFC-11 eq / kg)	0.53	6.82
Smog Potential (kg NOx eq / kg)	4.19	0.27
Small Dimension Lumber		
Weighted Resource Use kg	5.85	1.40
Global Warming Potential (kg CO2 eq / kg)	2.55	0.20
Acidification Potential (moles of H+ eq / kg)	2.04	0.12
Eutrophication Potential (kg N eq / kg)	0.08	2.04
Ozone Depletion Potential (kg CFC-11 eq / kg)	0.76	2.31
Smog Potential (kg NOx eq / kg)	2.61	0.09
Plywood		
Ozone Depletion Potential (kg CFC-11 eq / kg)	6.49	0.11

Sensitivity analysis is important when performing evaluations of this kind because it allows those using the impact assessment to understand what assemblies or components affect the various impacts of the final building profile. From an LCA modelling perspective, quantities of these sensitive materials included in the building may want to be double checked. From an a decision making perspective, the decision may be made to change the materials or design of the building to limit or eliminate the inclusion of these materials to lessen the negative environmental impacts of the building.

Potential Sources of Uncertainty:

- Overall:
    - Compounded error and uncertainty in our tools – On-Screen → IE → TRACI.
    - Local construction practices influence the potential negative effects of construction. For example, waste handling procedures on site (recycling programs, strictly dumping), truck idling policies etc.
    - The way you present your finding (per sq.ft., per occupant etc. can influence how the project findings are interpreted.

- On-Screen:
    - Every person undertaking takeoffs has different standards on accuracy. Error is thus potentially created when using the program.
    - Potential difference between drawings and as-built.
    - Photocopying images into PDF format may alter images slightly.
    - Lack of information regarding certain building details and components.
    - Extra joist reinforcing in the floor was not captured in the takeoffs because the floor was assumed and modeled in the IE as a standard joist floor input without the ability of such details to be accounted for.

- Impact Estimator Model:
    - Uses industry averages, actual materials/manufacturer may be better or worse than averages used.
    - The IE assumes material source and subsequent transportation costs which may not be representative of actual product.
    - Also, the IE assumes all impacts act at the site level, whereas cross country shipping exhausts pollutants the entire way. This may impact more sensitive ecosystems than the location of the building.
    - Impact factors are applied to products and the actual effects on a local scale may be more or less harmful depending on local situation.
    - The IE uses a waste factor to calculate construction waste which may not reflect on site practices/policies.

- Inflexibility in certain inputs with the IE, can’t always reflect precisely what is in place (e.g. only two types of paint, cannot choose no VOC surface treatments etc.)

Summary Graphs by Measure and Process Stage

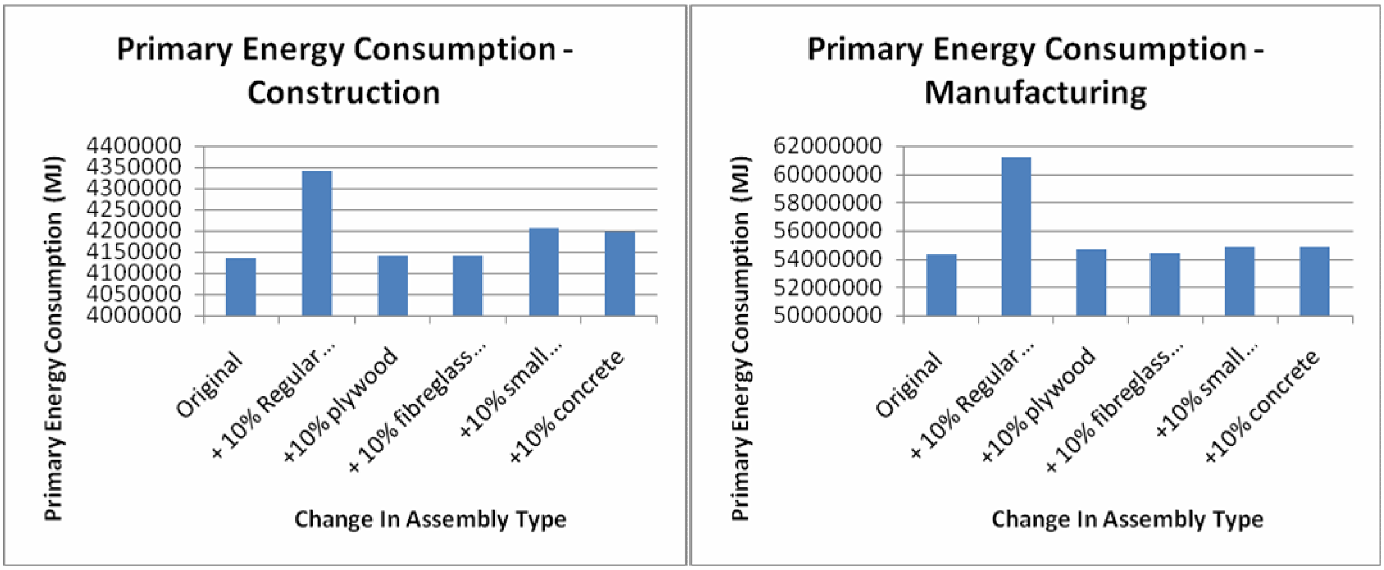

Figure 3: Primary Energy Consumption

Embodied primary energy includes all energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources. For example, natural gas used as a raw material in the production of various plastic (polymer) resins. In addition, the Impact Estimator captures the indirect energy use associated with processing, transporting, converting and delivering fuel and energy (Athena).

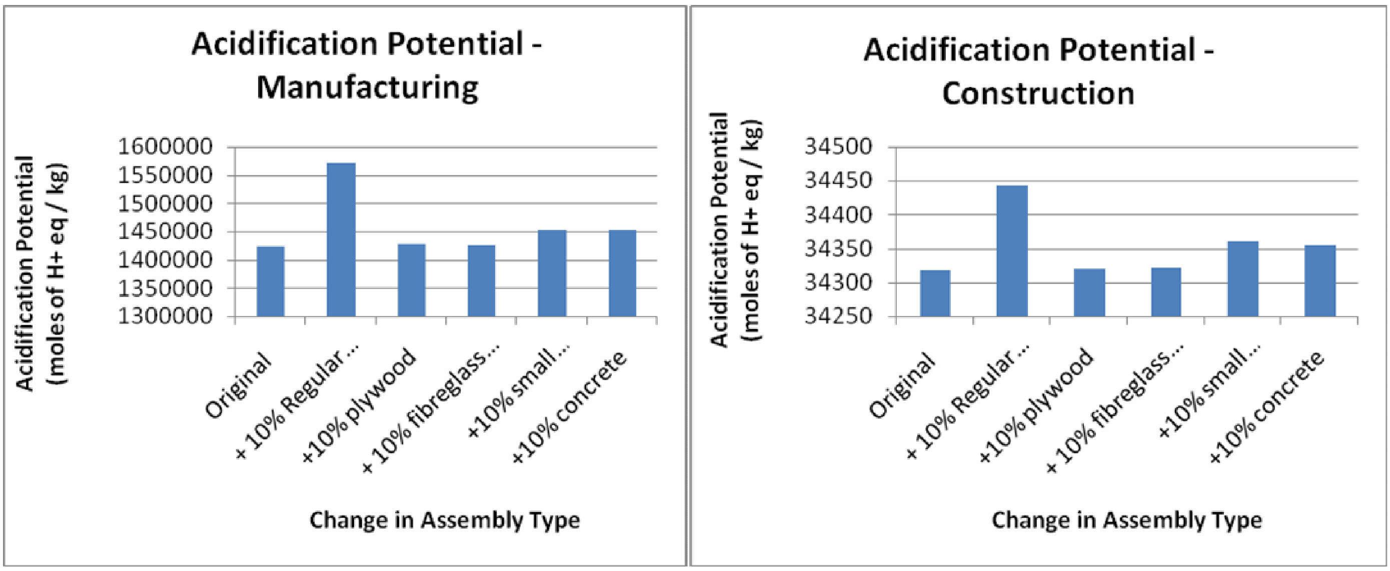

Figure 4: Acidification Potential

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

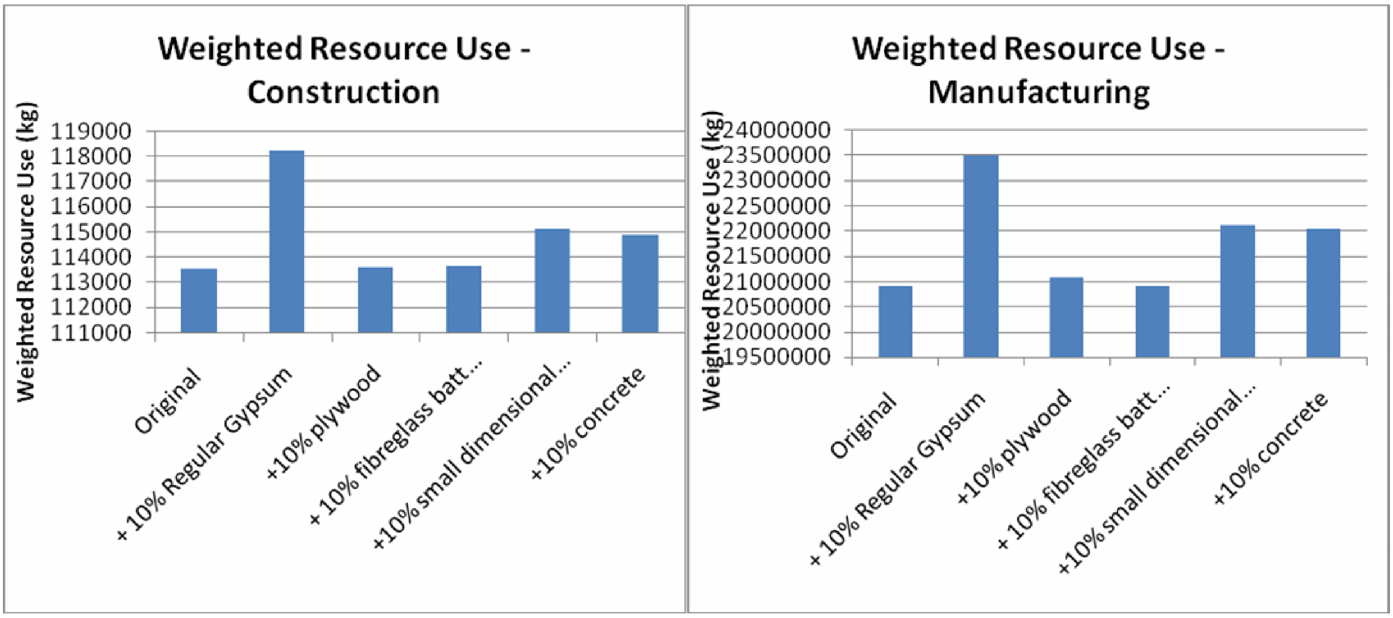

Figure 5: Weighted Resource Use

Raw resource use can be measured in common units such as tonnes, but a unit of one resource like iron ore is not at all comparable to a unit of another resource like timber or coal when it comes to environmental implications of extracting resources. Since the varied effects of resource extraction, (e.g., effects on bio-diversity, ground water quality and wildlife habitat, etc.) are a primary concern, we want to make sure they are taken into account. The problem is that while these ecological carrying capacity effects are as important as the basic life cycle inventory data, they are much harder to incorporate for a number of reasons, especially their highly site-specific nature.

Our approach was to survey a number of resource extraction and environmental specialists across Canada to develop subjective scores of the relative effects of different resource extraction activities. The scores reflect the expert panel ranking of the effects of extraction activities relative to each other for each of several impact dimensions. The scores were combined into a set of resource-specific index numbers, which are applied in the Impact Estimator as weights to the amounts of raw resources used to manufacture each building product. The Weighted Resource Use values reported by the Impact Estimator are the sum of the weighted resource requirements for all products used in each of the designs. They can be thought of as "ecologically weighted kilograms", where the weights reflect expert opinion about the relative ecological carrying capacity effects of extracting resources. Excluded from this measure are energy feedstocks used as raw materials. Except for coal, no scoring survey has been conducted on the effects of extracting fossil fuels, and hence, they have been assigned a score of one to only account for their mass. The weighting factor for each raw material is set out below (Athena):

Weighted Resource Use

Weighted Resource Use is the same as normal resource converted to mass quantities except for the following materials:

1. LIMESTONE * 1.5
2. IRON ORE * 2.25
3. COAL * 2.25
4. WOODFIBER * 2.5

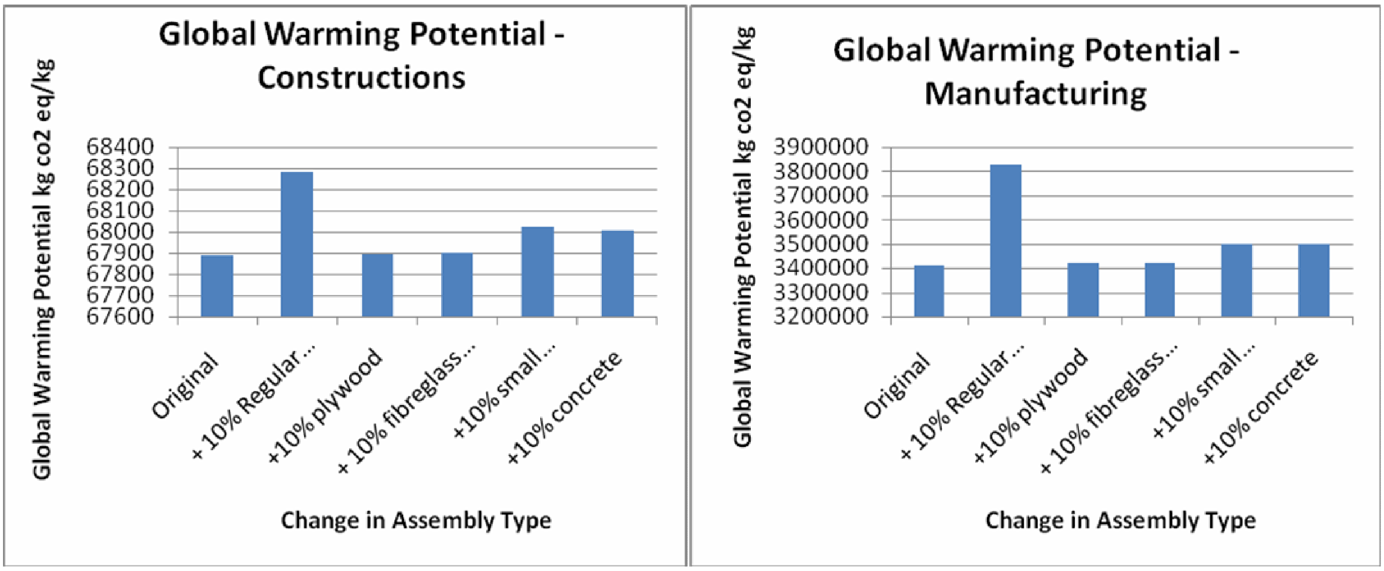

Figure 6: Global Warming Potential

Global warming potential (GWP) is a reference measure. The methodology and science behind the GWP calculation can be considered one of the most accepted impact assessment categories. GWP is expressed on an equivalency basis relative to CO_2 – in CO_2 equivalent kg.

Carbon dioxide is the common reference standard for global warming or greenhouse gas (GHG) effects. All other GHGs are referred to as having a "CO_2 equivalence effect" which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the various contributing gases over time.

As yet, no consensus has been reached among policy makers about the most appropriate time horizon for greenhouse gas calculations. The International Panel on Climate Change100-year time horizon figures have been used here as a basis for the equivalence index:

CO_2 eq kg = CO_2 kg + (CH_4 kg x 23) + (N_2O kg x 296)

While greenhouse gas emissions are largely a function of energy combustion, some products also emit greenhouse gases during the processing of raw materials. One example where process CO_2 emissions are significant is in the production of cement (calcination of limestone). Because the Impact Estimator uses data developed by a detailed life cycle modelling approach, all relevant process emissions of GHGs are included in the resultant GWP impact assessment category.

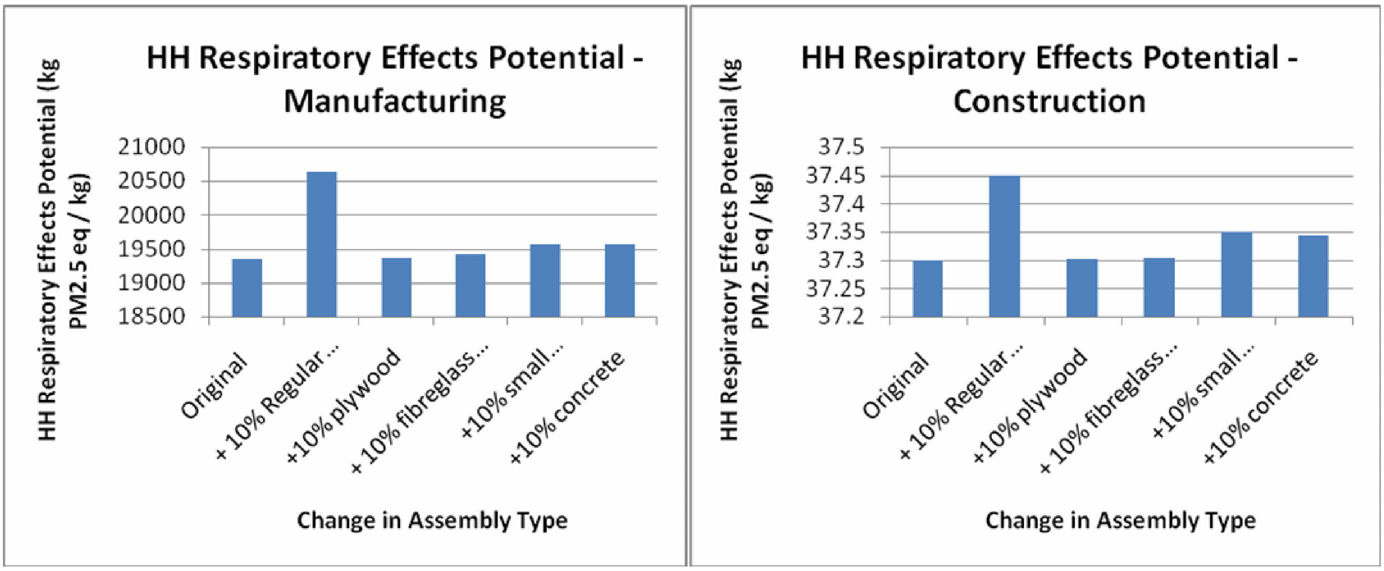

Figure 7: HH Respiratory Effects Potential

Particulate matter (PM) of various sizes (PM_{10} and $PM_{2.5}$) have considerable impact on human health. The EPA has identified "particulates" (from diesel fuel combustion) as the number one cause of human health deterioration due to its impact on the human respiratory system – asthma, bronchitis, acute pulmonary disease, etc. It should be mentioned that particulates are an important environmental output of plywood product production and need to be traced and addressed. The IE uses TRACI's "Human Health Particulates from Mobile Sources" characterization factor, on an equivalent $PM_{2.5}$ basis, in our final set of impact indicators (Athena).

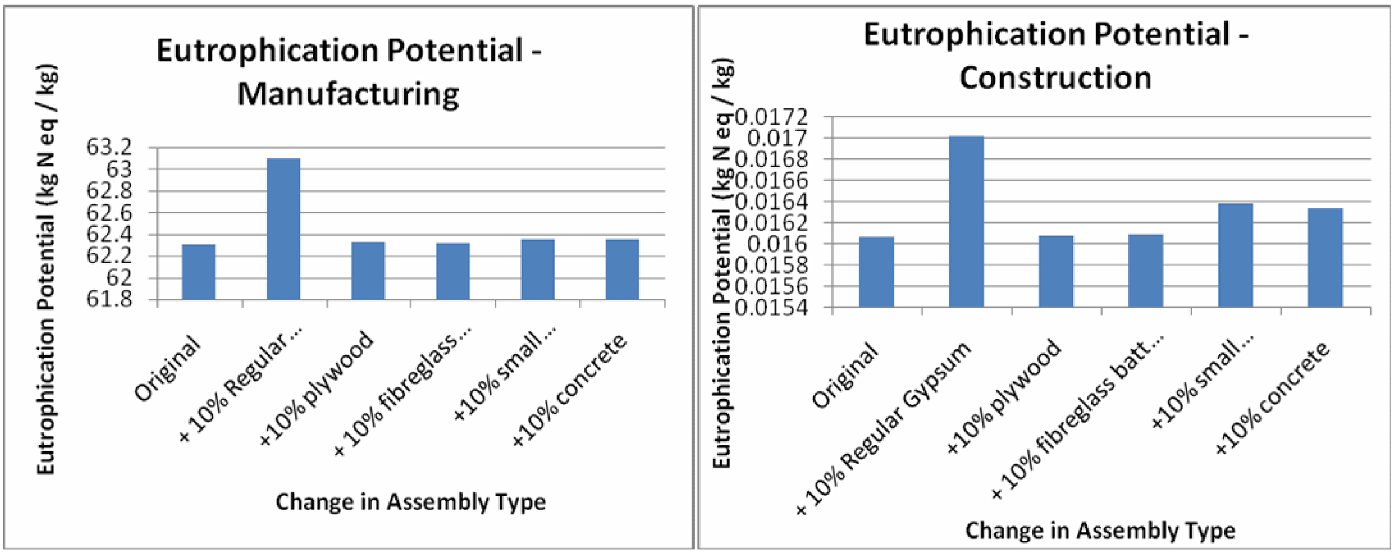

Figure 8: Eutrophication Potential

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

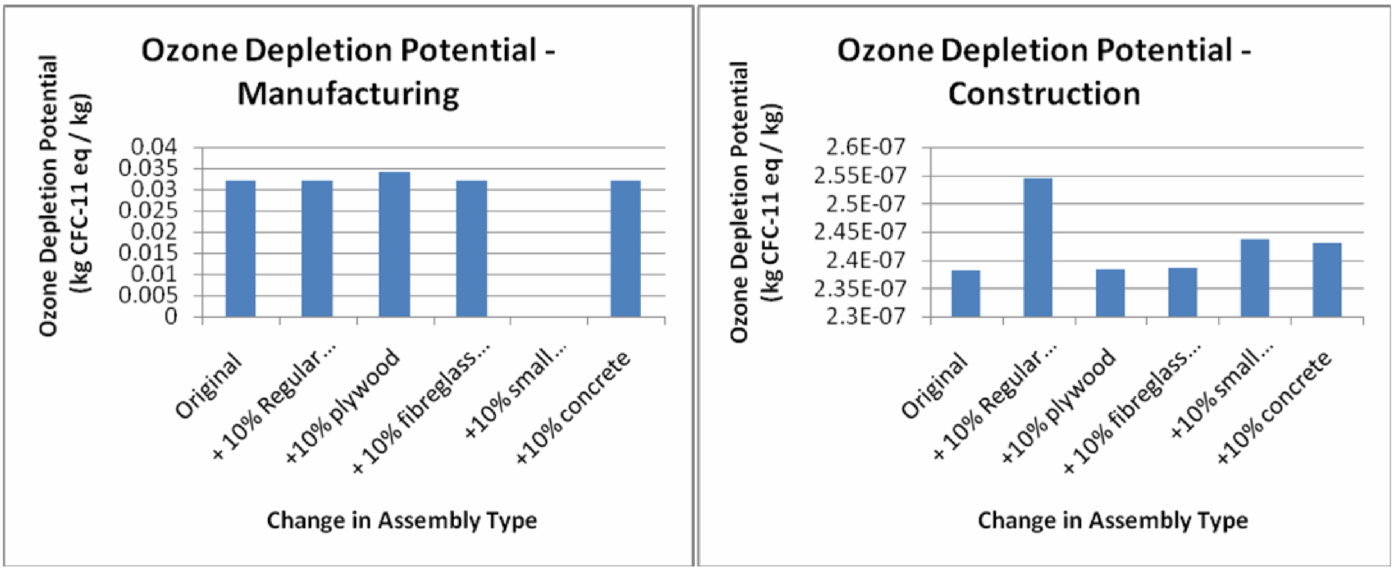

Figure 9: Ozone Depletion Potential

Stratospheric ozone depletion potential accounts for impacts related to the reduction of the protective ozone layer within the stratosphere caused by emissions of ozone depleting substances (CFCs, HFCs, and halons). The ozone depletion potential of each of the contributing substances is characterized relative to CFC-11, with the final impact indicator indicating mass (e.g., kg) of equivalent CFC-11 (Athena).

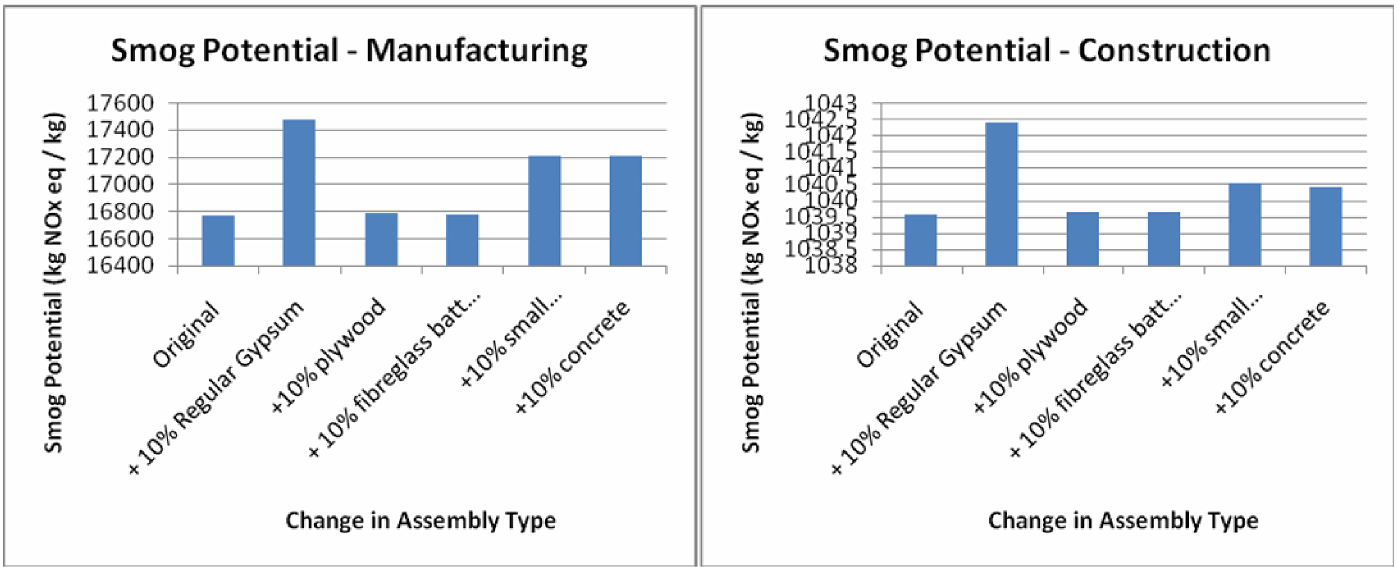

Figure 10: Smog Potential

Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The "smog" indicator is expressed on a mass of equivalent ethylene basis (Athena).

Table 4: Aggregated Residential Summary Measures

		Residences						
Impact Category	**Units**	**Vanier** 1959,1961,1968	**Totem** 1964	**Gage** 1972	**Fariview** 1985	**Thunderbird** 1995	**MarineDrive** 2005	**Average**
Primary Energy Consumption	MJ	288.43	404.14	328.49	282.91	495.45	963.82	460.54
Weighted Resource Use	kg	116.42	196.50	182.15	99.98	182.69	597.22	229.16
Global Warming Potential	(kg CO2 eq / kg)	20.11	29.56	25.64	16.74	28.40	77.88	33.05
Acidification Potential	(moles of H+ eq / kg)	3.66	10.13	10.65	7.03	6.10	27.03	10.77
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	0.05	0.08	0.13	0.09	0.07	0.26	0.12
Eutrophication Potential	(kg N eq / kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smog Potential	(kg NOx eq / kg)	0.06	0.14	0.18	0.09	0.10	0.42	0.16

Table 4 shows the aggregated summary measures of various residential developments on UBC Campus Vancouver, that are also part of the larger study. It is shown that the most energy intensive development is the Marine Drive Residences which consists of 6 concrete buildings and housing over 1600 students. The high primary energy is most likely due to the energy intensive concrete manufacturing process. Fairview is well below all the average summary measures for residential development potentially due to its wood frame construction. This summary shows that wood as a building material has a significantly reduced environmental footprint in the manufacturing and construction phase. The tradeoffs include less dense development as traditionally building codes specified a maximum of 4 stories for wood frame construction. However, recently the BC Building code has been amended to allow wood frame building up to 6 stories, reducing the urban density gap between wood frame and concrete construction.

Building Performance

An energy evaluation was undertaken to approximate the potential benefits of investing in alternate or additional materials for the development. The Fairview Crescent Housing Development evaluation looks at upgrading the insulation of the residence's envelope to increase operating energy efficiency. Operating energy for the entire development was obtained from UBC utilities.

The goal was to compare the operating energy of the building to the embodied energy invested in the building materials. This evaluation was then compared to the current UBC building development standards, the Residential Environmental Assessment Program (REAP) program. The theoretical operating energies for the two buildings were compared and a correlation between larger initial energy investments in better performing materials to the long run effectiveness of building performance was made. The energy payback period for the building upgrades were then approximated to determine how quickly the invested energy would be recovered in the form of conserved energy. The 'in place' wall materials are listed below with their general R-values.

Current Envelope R-Values

Table 5: Current Envelope R-Values

Walls		
Insulation Values	R/Value	
3" fibreglass batt	3.14/in	9.42
1" expanded polystyrene	5/in	5
1/2" drywall	0.45	0.45
Wood bevel siding	0.8	0.8
Int. Air film	0.68	0.68
Ext. Air film	0.17	0.17
	Total	**16.52**

Windows		
Standard glazing (double panes, 1/2" airspace)	2.04	2.04
Interior + exterior air film	0.85	0.85
	Total	**2.89**

Roof		
Asphalt	0.44	0.44
Sheathing 1/2"	0.63	0.63
6" fibreglass batt	3.14/in	18.84
Interior Air film	0.68	0.68
	Total	**20.59**

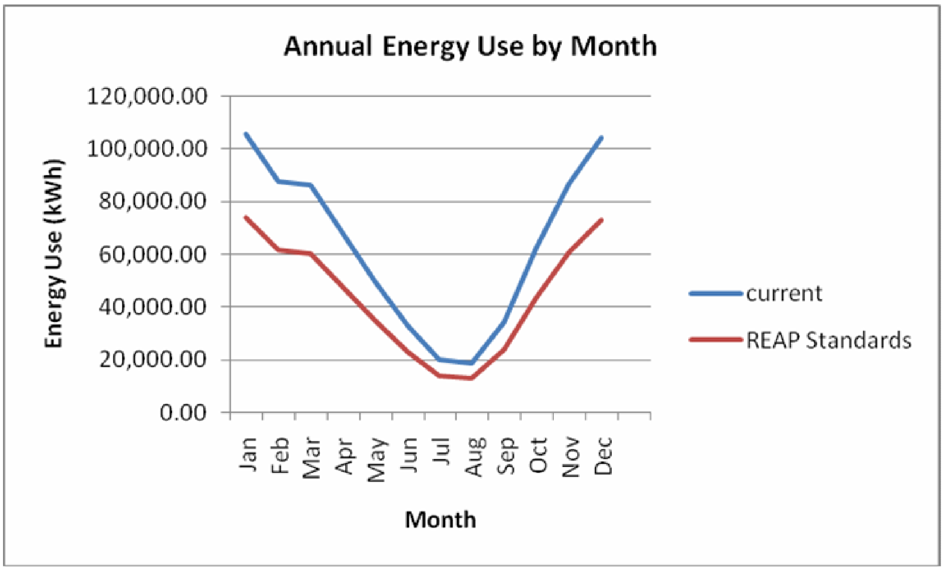

Figure 11: Current vs. REAP Standard Energy Use by Month

As interpreted from Figure 11, if the exterior insulation values of the building were to be improved to the current REAP standards, the building's energy usage would decrease from 2,724 GJ to 1,915 GJ. This corresponds to a reduction of nearly 43% in the building's energy use by upgrading the exterior components of the building.

Energy used to heat and cool the residences is one of the largest contributors to operating energy for the building. The most significant contributions to the wall's R-value come from the 1" extruded polystyrene and fibreglass batt insulation. To maximize further energy efficiency gains, the most logical suggestion would be to further increase wall insulation values. The increased insulation of the exterior walls would reduce energy loss in the winter and gains in the summer, thus reducing the need to mechanically heat and cool to residences. There are several practical ways that insulation could be added to the existing building to improve it's envelope performance.

Since the exterior walls are 2x4" studs, the maximum allowable space for insulation within the wall is 3 ½". So there is little or no room to add fibreglass batt insulation given the current wall configurations. One solution to this problem could be to add 1" extruded polystyrene insulation to the interior part of the exterior walls. This would slightly reduce interior floor space, but the wall R value would increase the building's overall R-value from 16.30 to 19.22. Furthermore, an additional 3.5" of insulation in the attic would increase the weighted average of the building's overall insulation value to approximately 22.61, which correlates to 97.3 % of the REAP standards.

There may be a slight underestimation of the exterior wall insulation values because the fibreglass batt insulation was modeled as 3". The wall specifications simply noted R10 batt insulation for exterior walls. Upon investigation, the corresponding thickness of fibreglass batt insulation to achieve the same R10 batt insulation values resulted in 3" fibreglass batt insulation.

There are several other factors to consider when deciding to renovate for increased energy efficiency. The feasibility of the renovations and a full evaluation of cost to benefits would need to be considered. However, the energy and cost savings are a big incentive to improve energy efficiency and Figure 12 shows that it would take approximately 43 months to recover the additional initial investment in embodied energy. The initial energy invested in materials is roughly 3.08 GJ higher with the improved building envelope.

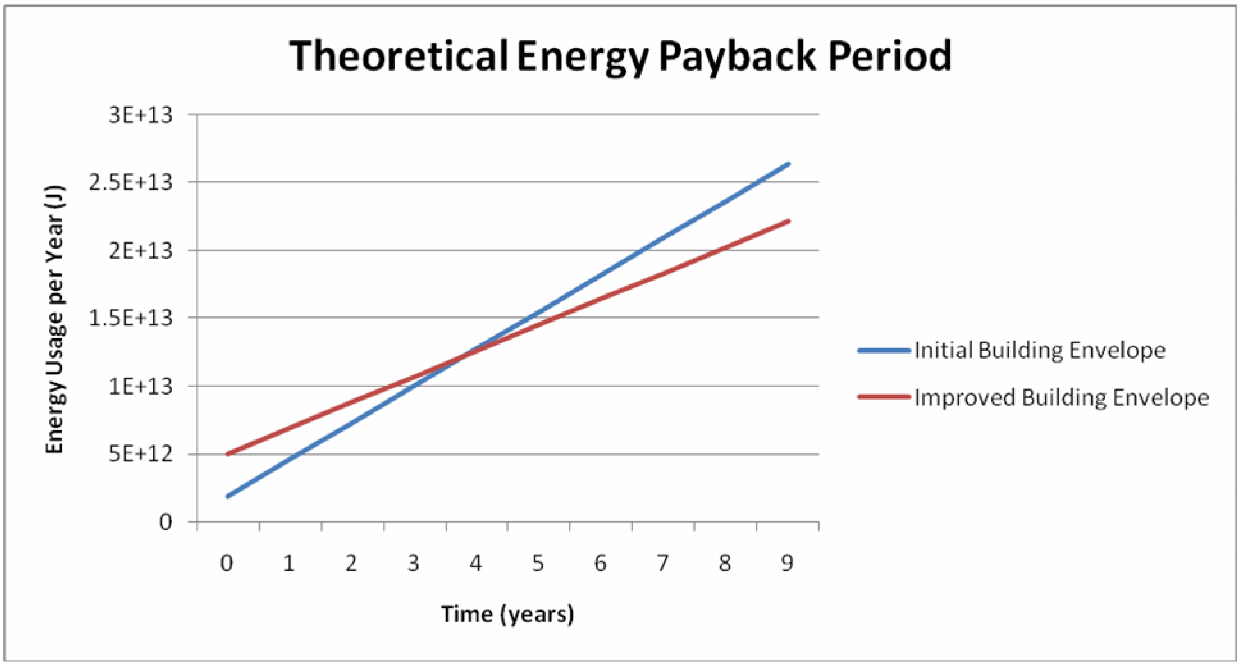

Figure 12: Theoretical Energy Payback Period

Below, table 5 shows the estimation of material amounts and costs needed to upgrade the roof insulation by 3.5” fibreglass batt insulation and add 1” extruded polystyrene to the exterior walls.

Table 6: Material Upgrade Costs

Exterior Wall Insulation Upgrade Costing	
Total Ext. Wall Area (sq.ft)	156085
Extruded Polystyrene Area/Panel (sq.ft)	150
Cost per Panel ($)	58.27
# Panels Needed	1040.57
Rough Cost Material ($)	**60633.82**
Roof Area Insulation Upgrade Costing	
Total Roof Area (sq.ft)	82500
Area of 3.5" Fibreglass Batt per Roll (sq.ft.)	98
Cost per Roll ($)	31.47
# Rolls Needed	841.84
Rough Cost Material ($)	**26492.60**
Total Cost of Upgrades ($)	**87126.42**

Conclusions

This analysis of the Fairview Crescent Student Housing Development used OnScreen Takeoff Software to create a material list for the development. This material list, supplemented with specific assembly details obtained from architectural and structural drawings, was inputted into Athena Institute's Impact Estimator software. The IE uses the TRACI impact assessment methodology to quantify the environmental impacts of the building assemblies.

The outputs from the IE include a final Bill of Materials and summary measures by life cycle stage and assembly group. The information obtained in this analysis will be used in conjunction with the information created from additional reports produced in CIVL 498C to analyze the potential environmental impacts of different building types on campus. The summary measures by life cycle stage showed the majority of the environmental impacts are associated with the manufacturing stage of the building. In addition, the assembly group with the largest primary energy usage is the roof assembly. This is most likely due to the significant amount of asphalt shingles and fibreglass batt insulation incorporated in this assembly.

A sensitivity analysis was undertaken on the 5 most prevalent materials to investigate the relative impacts each material has on the development's overall environmental impact. It was determined that the most influential component out of the five chosen was the interior gypsum board. This is due in part to the significant amount incorporated in the development and the large primary energy needed in the manufacturing stage as well as the significant acidification, HH potential, weighted resource use and global warming potential effects.

In addition, an energy analysis was undertaken to determine the relationship between better performing, higher embodied energy materials and the operating energy associated with space heating. The amount and cost of materials needed to improve the current buildings energy performance to UBC's current building energy standards, REAP, were calculated in the model. It was determined that the addition of 1" extruded polystyrene to the exterior walls and an additional 3.5" of R-10 fibreglass batt in the roof assembly could improve the energy performance to REAP standards. An estimate of the additional materials based on retail material costs is $87 000. It was also found the energy payback period for the embodied energy would be approximately 43 months. This estimate offers a rough first look at this potential for saving energy and a more detailed investigation would be necessary if it is to be pursued.

Since the service life of the development could be extended for many more decades, it seems reasonable to consider further feasibility analysis into building efficiency upgrades. There is decreasing availability for new areas to develop at UBC's Vancouver campus and soon development will shift its focus even more intensely on retrofit and upgrade. The relatively simple and inexpensive upgrades to the Fairview Crescent Student Housing Development can save significant amounts of operating energy and should be considered more in depth in the future.

Appendix A – Impact Estimator Input Tables

Assembly Group	Assembly Type	Assembly Name	Input Fields	Input Values	
				Known/Measured	**EIE Inputs**
A.2 Walls					
	A.2.1 Exterior Light Wood Frame				
		A.2.1.1 - A unit 1st Floor (with brick facade)			
			Wall Type	Exterior	Exterior
			Length (ft)	118	118
			Height (ft)	9.25	9.25
		Windows	Number of Windows	30	30
			Total Window Area (ft2)	196	196
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Doors	Number of Doors	5	5
			Door Type	-	Steel Exterior, 50% glazing
		Envelope	Category	Exterior Insulation	Exterior Insulation
			Material	Rigid Insulation	Expanded Polystyrene
			Thickness	1"	1"
			Category	Gypsum Board	Gypsum Board
			Material	Dry Wall	Gypsum Regular
			Thickness	1/2"	1/2"
			Category	Cladding	Cladding
			Material	Brick	brick (modular-metric)
			Thickness (in)	-	-
			Category	Insulation	Insulation
			Material	R10 Batt insulation	Fiberglass batt
			Thickness (in)	-	3
			Category	Vapour Barrier	Vapour Barrier
			Material	-	polyethylene
			Thickness (mm)	4	3
		A.2.1.2 (a-d) - A unit 2nd and 3rd Floor (with wood facade)			
			Wall Type	Exterior	Exterior
			Length (ft)	480	480

		Height (ft)	8.6	8.6
	Windows	Number of Windows	66	66
		Total Window Area (ft2)	560	560
		Operable?	Yes	Yes
		Frame Type	Aluminium	Aluminium
		Glazing Type	-	Standard Glazing
	Envelope	Category	Exterior Insulation	Exterior Insulation
		Material	Rigid Insulation	Expanded Polystyrene
		Thickness	1"	1"
		Category	Gypsum Board	Gypsum Board
		Material	Drywall	Gypsum Regular
		Thickness	1/2"	1/2"
		Category	Cladding	Cladding
		Material	Wood Siding	Wood Bevel Siding - Pine
		Thickness (in)	-	-
		Category	Insulation	Insulation
		Material	R10 Batt insulation	Fiberglass batt
		Thickness (in)	-	3
		Category	Vapour Barrier	Vapour Barrier
		Material	-	polyethylene
		Thickness (mm)	4	3
	A.2.1.2 (e-g) - A unit 2nd and 3rd Floor (with gypsum facade)			
		Wall Type	Exterior	Exterior
		Length (ft)	480	480
		Height (ft)	8.6	8.6
	Windows	Number of Windows	66	66
		Total Window Area (ft2)	560	560
		Operable	Yes	Yes
		Frame Type	Aluminium	Aluminium
		Glazing Type	-	Standard Glazing
	Envelope	Category	Exterior Insulation	Exterior Insulation
		Material	Rigid Insulation	Expanded Polystyrene
		Thickness	1"	1"
		Category	Gypsum Board	Gypsum Board
		Material	Drywall	Gypsum Regular
		Thickness	1/2"	1/2"
		Category	Cladding	Cladding
		Material	Exterior Gypsum Board	Exterior Gypsum Board
		Thickness (in)	1/2"	1/2"
		Category	Insulation	Insulation

		Material Thickness (in)	R10 Batt insulation -	Fiberglass batt 3
		Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
	B.2.1.1 - B unit 1st Floor (with brick facade)			
		Wall Type	Exterior	Exterior
		Length (ft) Height (ft)	118 9.25	118 9.25
	Windows	Number of Windows Total Window Area (ft2)	34 190	34 190
		Frame Type Glazing Type	Aluminium Standard Glazing	Aluminium Standard Glazing
	Doors	Number of Doors Door Type	2 -	24 Steel Exterior, 50% glazing
	Envelope	Category Material Thickness	Exterior Insulation Rigid Insulation 1"	Exterior Insulation Expanded Polystyrene 1"
		Category Material Thickness	Gypsum Board Dry Wall 1/2"	Gypsum Board Gypsum Regular 1/2"
		Category Material Thickness (in)	Cladding Brick -	Cladding brick (modular-metric) -
		Category Material Thickness (in)	Insulation R10 Batt insulation -	Insulation Fiberglass batt 3
		Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
	B.2.1.2 (a-g) - B unit 2nd and 3rd Floor (with wood facade)			
		Wall Type	Exterior	Exterior
		Length (ft) Height (ft)	210 8.63	210 8.63
	Windows	Number of Windows Total Window Area (ft2)	70 372	70 372
		Operable? Frame Type Glazing Type	Yes Aluminium -	Yes Aluminium Standard Glazing
	Envelope	Category	Exterior Insulation	Exterior Insulation

	Material Thickness	Rigid Insulation 1"	Expanded Polystyrene 1"
	Category Material Thickness	Gypsum Board Drywall 1/2"	Gypsum Board Gypsum Regular 1/2"
	Category Material Thickness (in)	Cladding Wood Siding -	Cladding Wood Bevel Siding - Pine -
	Category Material Thickness (in)	Insulation R10 Batt insulation -	Insulation Fiberglass batt 3
	Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
B.2.1.2 (h-i) - B unit 2nd and 3rd Floor (with Gypsum Facade)			
Windows	Wall Type	Exterior	Exterior
	Length (ft)	210	210
	Height (ft)	8.63	8.63
	Number of Windows	70	70
	Total Window Area (ft2)	372	372
	Operable? Frame Type Glazing Type	Yes Aluminium -	Yes Aluminium Standard Glazing
Envelope	Category Material Thickness	Exterior Insulation Rigid Insulation 1"	Exterior Insulation Expanded Polystyrene 1"
	Category Material Thickness	Gypsum Board Drywall 1/2"	Gypsum Board Gypsum Regular 1/2"
	Category Material Thickness (in)	Cladding Exterior Gypsum Board 1/2"	Cladding Exterior Gypsum Board 1/2"
	Category Material Thickness (in)	Insulation R10 Batt insulation -	Insulation Fiberglass batt 3
	Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
B.2.1.3 - B unit End Wall 1st Floor (with			

Brick Facade)			
Windows	Wall Type	Exterior	Exterior
	Length (ft)	37	37
	Height (ft)	9.25	9.25
	Number of Windows	15	15
	Total Window Area (ft2)	60	60
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Doors	Number of Doors	0	0
	Door Type	-	-
Envelope	Category	Exterior Insulation	Exterior Insulation
	Material	Rigid Insulation	Expanded Polystyrene
	Thickness	1"	1"
	Category	Gypsum board	Gypsum board
	Material	Drywall	Gysum Regular
	Thickness	1/2"	1/2"
	Category	Cladding	Cladding
	Material	Brick	Brick (modular-metric)
	Thickness (in)	-	-
	Category	Insulation	Insulation
	Material	R10 Batt insulation	Fiberglass batt
	Thickness (in)	-	3
	Category	Vapour Barrier	Vapour Barrier
	Material	-	polyethylene
	Thickness (mm)	4	3
B.2.1.4 - B unit End Wall 2nd & 3rd Floor (with Wood Facade)			
Windows	Wall Type	Exterior	Exterior
	Length (ft)	74	74
	Height (ft)	8.35	8.35
	Number of Windows	12	12
	Total Window Area (ft2)	57	57
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Doors	Number of Doors	0	0
	Door Type	-	-
Envelope	Category	Exterior Insulation	Exterior Insulation
	Material	Rigid Insulation	Expanded Polystyrene
	Thickness	1"	1"
	Category	Gypsum board	Gypsum board
	Material	Drywall	Gysum Regular 1/2"
	Thickness	1/2"	-

		Category	Cladding	Cladding
		Material	Wood Siding	Wood Bevel Siding - Pine
		Thickness (in)	-	-
		Category	Insulation	Insulation
		Material	R10 Batt insulation	Fiberglass batt
		Thickness (in)	-	3
		Category	Vapour Barrier	Vapour Barrier
		Material	-	polyethylene
		Thickness (mm)	4	3
	C.2.1.1 - C unit 1st Floor (with brick facade)			
		Wall Type	Exterior	Exterior
		Length (ft)	187	187
		Height (ft)	9.27	9.27
	Windows	Number of Windows	46	46
		Total Window Area (ft2)	310	310
		Frame Type	Aluminium	Aluminium
		Glazing Type	-	Standard Glazing
	Doors	Number of Doors	2	26
		Door Type	-	Steel Exterior, 50% glazing
	Envelope	Category	Gypsum Board	Gypsum Board
		Material	Dry Wall	Gypsum Regular
		Thickness	1/2"	1/2"
		Category	Exterior Insulation	Exterior Insulation
		Material	Rigid Insulation	Expanded Polystyrene
		Thickness	1"	1"
		Category	Cladding	Cladding
		Material	Brick	brick (modular-metric)
		Thickness (in)	-	-
		Category	Insulation	Insulation
		Material	R10 Batt insulation	Fiberglass batt
		Thickness (in)	-	3
		Category	Vapour Barrier	Vapour Barrier
		Material	-	polyethylene
		Thickness (mm)	4	3
	C.2.1.2 (a-j) - C unit 2nd and 3rd Floor (with wood facade)			
		Wall Type	Exterior	Exterior
		Length (ft)	380	380
		Height (ft)	8.58	8.58

	Windows	Number of Windows	99	99
		Total Window Area (ft2)	770	770
		Operable?	Yes	Yes
		Frame Type	Aluminium	Aluminium
		Glazing Type	-	Standard Glazing
	Envelope	Category	Exterior Insulation	Exterior Insulation
		Material	Rigid Insulation	Expanded Polystyrene
		Thickness	1"	1"
		Category	Gypsum Board	Gypsum Board
		Material	Drywall	Gypsum Regular
		Thickness	1/2"	1/2"
		Category	Cladding	Cladding
		Material	Wood Siding	Wood Bevel Siding - Pine
		Thickness (in)	-	-
		Category	Insulation	Insulation
		Material	R10 Batt insulation	Fiberglass batt
		Thickness (in)	-	3
		Category	Vapour Barrier	Vapour Barrier
		Material	-	polyethylene
		Thickness (mm)	4	3
	C.2.1.2 (k-m) - C unit 2nd and 3rd Floor (with gypsum facade)			
		Wall Type	Exterior	Exterior
		Length (ft)	380	380
		Height (ft)	8.58	8.58
	Windows	Number of Windows	99	99
		Total Window Area (ft2)	770	770
		Operable?	Yes	Yes
		Frame Type	Aluminium	Aluminium
		Glazing Type	-	Standard Glazing
	Envelope	Category	Exterior Insulation	Exterior Insulation
		Material	Rigid Insulation	Expanded Polystyrene
		Thickness	1"	1"
		Category	Gypsum Board	Gypsum Board
		Material	Drywall	Gypsum Regular
		Thickness	1/2"	1/2"
		Category	Cladding	Cladding
		Material	Exterior Gypsum Board	Exterior Gypsum Board
		Thickness (in)	1/2"	1/2"
		Category	Insulation	Insulation
		Material	R10 Batt insulation	Fiberglass batt

		Thickness (in)	-	3
		Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
	C.2.1.3 - C unit End Wall 1st Floor (with brick facade)			
		Wall Type	Exterior	Exterior
		Length (ft) Height (ft)	65 9.27	65 9.27
	Windows	Number of Windows Total Window Area (ft2)	13 70	13 70
		Frame Type Glazing Type	Aluminium Standard Glazing	Aluminium Standard Glazing
	Doors	Number of Doors Door Type	0 -	0 -
	Envelope	Category Material Thickness	Exterior Insulation - 1"	Exterior Insulation Expanded Polystyrene 1"
		Category Material Thickness	Gypsum board Drywall 1/2"	Gypsum board Gysum Regular 1/2"
		Category Material Thickness (in)	Cladding Brick -	Cladding Brick (modular-metric) -
		Category Material Thickness (in)	Insulation R10 Batt insulation -	Insulation Fiberglass batt 3
		Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
	C.2.1.4 - C unit End Wall 2nd & 3rd Floor (with Wood Facade)			
		Wall Type	Exterior	Exterior
		Length (ft) Height (ft)	130 8.57	130 8.57
	Windows	Number of Windows Total Window Area (ft2)	12 61	12 61
		Frame Type Glazing Type	Aluminium Standard Glazing	Aluminium Standard Glazing
	Doors	Number of Doors Door Type	0 -	0 -
	Envelope	Category	Exterior Insulation	Exterior Insulation

		Material Thickness	- 1"	Expanded Polystyrene 1"
		Category Material Thickness	Gypsum board Drywall 1/2"	Gypsum board Gysum Regular 1/2" -
		Category Material Thickness (in)	Cladding Wood Siding -	Cladding Wood Bevel Siding - Pine -
		Category Material Thickness (in)	Insulation R10 Batt insulation -	Insulation Fiberglass batt 3
		Category Material Thickness (mm)	Vapour Barrier - 4	Vapour Barrier polyethylene 3
A.2.2 Interior Light Wood Frame				
	A.2.2.1 - A unit Interior Load Bearing Walls (3 Floors)			
		Wall Type	Interior	Interior
		Length (ft) Height (ft)	2115 8.81	21150 8.81
	Doors	Number of Interior Doors Door Type	35 -	35 Hollow Core Wood Interior
	Sheathing	Gypsum Board (2x for each side of wall)	1/2" Drywall	1/2" gypsum regular
	Framing	Stud thickness Stud Spacing (in o.c.) Stud Type	2x4 16 wood	2x4 16 wood
	B.2.2.1 - B unit Interior Load Bearing Walls (3 Floors)			
		Wall Type	Interior	Interior
		Length (ft) Height (ft)	1776 8.83	1776 8.83
	Doors	Number of Interior Doors Door Type	28 -	28 Hollow Core Wood Interior
	Sheathing	Gypsum Board (2x for each side of wall)	1/2" Drywall	1/2" gypsum regular
	Framing	Stud thickness	2x4	2x4

		Stud Spacing (in o.c.)	16	16
		Stud Type	-	Green
	C.2.2.1 - C unit Interior Load Bearing Walls (3 Floors)			
		Wall Type	Interior	Interior
		Length (ft)	1076	1076
		Height (ft)	8.83	8.83
	Doors	Number of Interior Doors	38	38
		Door Type	-	Hollow Core Wood Interior
	Sheathing	Gypsum Board (2x for each side of wall)	1/2" gypsum regular	1/2" gypsum regular
	Framing	Stud thickness	2x4	2x4
		Stud Spacing (in o.c.)	16	16
		Stud Type	-	Green
	2.3 Concrete Parking Garage			
	2.3.1 Concrete Parking Garage Walls			
		Length (ft)	2000	2000
		Height (ft)	8.5	8.5
		Concrete Flyash Content	Average	Average
		Thickness (in)	8	8
		Strength (psi)	-	3000
		Reinforcement	-	#5
		Vapour Barrier	6	6
A.3 Roof				
	A.3.1 Wood Truss			
	A.3.1.1 - A unit Roof Main Span			
		Roof Width	45	45
		Span (ft)	45	45
		Decking Type	plywood	plywood
		Decking Thickness (in)	1/2	1/2
		Live Load	45	45
		Roof Envelope	asphalt shingle	asphalt shingle
		Vapour Barrier	6 mil poly	6 mil poly
		Gypsum Board	1/2" Drywall	1/2" regular
		Insulation	R20 Batt Insulation	fibreglass batt 6"
	A.3.1.2 - A unit Roof Overhangs			
		Roof Width (avg)	55	550
		Span (ft) (avg)	12	12

	Decking Type Decking Thickness	plywood 1/2	plywood 1/2
	Live Load (kip)	45	45
Envelope	Roof Envelope	asphalt shingle	asphalt shingle
	Vapour Barrier	6 mil poly	6 mil poly
	Gypsum Board	1/2" Drywall	1/2" regular
	Insulation	R20 Batt Insulation	fibreglass batt 6"
B.3.1.1 - B unit Roof Main Span			
	Roof Width Span (ft)	35 42	35 42
	Decking Type Decking Thickness (in)	` 1/2	plywood 1/2
	Live Load	40	45
Envelope	Roof Envelope	asphalt shingle	asphalt shingle
	Vapour Barrier	6 mil poly	6 mil poly
	Gypsum Board	1/2" regular	1/2" regular
	Insulation	R20 Batt Insulation	fibreglass batt 6"
B.3.1.2 - B unit Roof Overhangs			
	Roof Width (avg) Span (ft) (avg)	37 12	37 12
	Decking Type Decking Thickness	plywood 1/2	plywood 1/2
	Live Load (kip)	45	45
Envelope	Roof Envelope	asphalt shingle	asphalt shingle
	Vapour Barrier	6 mil poly	6 mil poly
	Gypsum Board	1/2" regular	1/2" regular
	Insulation	R20 Batt Insulation	fibreglass batt 6"
C.3.1.1 - C unit Roof Main Span			
	Roof Width Span (ft)	60 42	60 42
	Decking Type Decking Thickness (in)	plywood 1/2	plywood 1/2
	Live Load	45	45
Envelope	Roof Envelope	asphalt shingle	asphalt shingle
	Vapour Barrier	6 mil poly	6 mil poly
	Gypsum Board	1/2" regular	1/2" regular
	Insulation	R20 Batt Insulation	fibreglass batt 6"
C.3.1.2 - C unit Roof Overhangs			

			Roof Width (avg) Span (ft) (avg)	108 6	108 6
			Decking Type Decking Thickness	plywood 1/2	plywood 1/2
			Live Load (kip)	45	45
		Envelope	Roof Envelope	asphalt shingle	asphalt shingle
			Vapour Barrier	6 mil poly	6 mil poly
			Gypsum Board	1/2" regular	1/2" regular
			Insulation	R20 Batt Insulation	fibreglass batt 6"
	3.2 Concrete Parking Structure				
		3.2.1 Concrete Parking Garage Roof			
			Number of Rows Roof Area Concrete Strength (psi) Concrete Flyash	- 52622 - Average	47 56398.15 3000 Average
A.4 Floors					
	A.4.1 Wood I-Joist				
		A.4.1.1 - A unit 2nd Floor			
			Width (avg) Span (avg)	105 22	105 22
		Decking	Decking Type Decking Thickness	plywood 3/4"	plywood 3/4"
			Gypsum Board	Gypsum Regular 1/2"	Gypsum Regular 1/2"
		Web	Web Type Web Thickness	- 1/2"	plywood 1/2"
		Flange	Flange Type Flange Size	- 2.5"x1.5"	MSR 2.5"x1.5"
			Live Load	70	75
		A.4.1.2 - A unit 3rd Floor			
			Width (avg) Span (avg)	44 22	440 22
		Decking	Decking Type Decking Thickness	plywood 3/4"	plywood 3/4"
			Gypsum Board	Gypsum Regular 1/2"	Gypsum Regular 1/2"
		Web	Web Type Web Thickness	- 1/2"	plywood 1/2"
		Flange	Flange Type Flange Size	- 2.5"x1.5"	MSR 2.5"x1.5"
			Live Load	40	45
		B.4.1.1 - B unit 2nd Floor			
			Width (avg)	97	1164

		Span (avg)	15	15
	Decking	Decking Type	plywood	plywood
		Decking Thickness	3/4"	3/4"
		Gypsum Board	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Web	Web Type	-	plywood
		Web Thickness	1/2"	1/2"
	Flange	Flange Type	-	MSR
		Flange Size	2.5"x1.5"	2.5"x1.5"
		Live Load	70	75
	B.4.1.2 - B unit 3rd Floor			
		Width (avg)	97	1164
		Span (avg)	15	15
	Decking	Decking Type	plywood	plywood
		Decking Thickness	3/4"	3/4"
		Gypsum Board	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Web	Web Type	-	plywood
		Web Thickness	1/2"	1/2"
	Flange	Flange Type	-	MSR
		Flange Size	2.5"x1.5"	2.5"x1.5"
		Live Load	40	45
	C.4.1.1 - C unit 2nd Floor			
		Width (avg)	105	1365
		Span (avg)	22	22
	Decking	Decking Type	plywood	plywood
		Decking Thickness	3/4"	3/4"
		Gypsum Board	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Web	Web Type	-	plywood
		Web Thickness	1/2"	1/2"
	Flange	Flange Type	-	MSR
		Flange Size	2.5"x1.5"	2.5"x1.5"
		Live Load	70	75
	C.4.1.2 - C unit 3rd Floor			
		Width (avg)	105	1365
		Span (avg)	22	22
	Decking	Decking Type	plywood	plywood
		Decking Thickness	3/4"	3/4"
		Gypsum Board	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Web	Web Type	-	plywood
		Web Thickness	1/2"	1/2"
	Flange	Flange Type	-	MSR
		Flange Size	2.5"x1.5"	2.5"x1.5"

			Live Load	40	45
	4.2 Concrete Parking Structure				
		4.2.1 Concrete Parking Garage Floor			
			Number of Rows	-	47
			Roof Area	52622	56398.15
			Concrete Strength (psi)	-	3000
			Concrete Flyash	Average	Average
			Polyethylene (mm)	6	6
5 Extra Materials					
	5.1 Wood				
		D.5.1.1 - Stairs			
			Vol. Wood (Mbfm)	**5.11**	
		D.5.1.2 Dividing Walls			
			Total Volume (Mbfm)	**28.21185**	
	5.2 Concrete				
		D.5.2.1 Total Concrete Floor Topping For All Units			
			Concrete Volume (yd^3)	**326.2**	
		D.5.2.2 Total Slab on Grade Concrete			
			All units (yd3)	**627.8**	
		D.5.2.3 - Concrete Footing Slab on Grade			
			Total Volume Concrete (yd3)	**90**	
		D.5.2.4 Block Walls (8x8x16" blk)			
			Total Blocks	2932	
			Total Volume Mortar (yd3)	**0.0306**	
	5.3 Gypsum				
		D.5.3.1 - Interior Wall Gypsum			
			Total Wall Area (includes both sides of wall) (ft2)	**77704**	
	5.4 Steel				
		D 5.4.1 - Rebar Slab on Grade			
			Total (tons)	**3.2**	

Appendix B – Impact Estimator Input Assumption Document

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Foundation			Concrete SOGs were accounted for using area conditions, since takeoffs for SOGs require a length, width and thickness measurements. In the Impact Estimator, SOG inputs are limited to being either a 4" or 8" thickness. Since the actual SOG thicknesses for the Fairview buildings were not exactly 4" or 8" thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. Foundations for blocks Y,V,X and W are slab on grade, whereas the buildings in U and Z are built on top of an underground parking garage. The slab on grade construction consists of footings and a slab. Area conditions were used for the slab and then multiplied by the thickness to generate the volume of additional concrete for slab on grade. Linear conditions were used to generate the length of footings and then multiplied by the cross sectional area of the footing to generate the volume of concrete. The concrete and rebar reinforcing for the parking garage were modeled using the parking garage option in Athena. Athena uses the number of parking spaces as the input to model a parking garage and then generates an area corresponding to the number of stalls. Since the number of stalls incorporated in the Fairview parking garage did not correspond to the assumptions made in the Athena model, the 'correct' number of stalls necessary to produce the gross floor area found in the Fairview Parking garage was reverse engineered.
2 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 areas of the window openings. Envelope and opening details were sourced from architectural drawings provided by the planning office and site visits were also conducted to determine information not included in the drawings. A few assumptions and calculations were made in order to complete modeling of the walls for the Fairview Residence. Different facade treatments were used on different buildings and at different heights on the building for architectural effect. For example, the first floor of most units are cladded in modular brick and the second and third floors vary between wood bevel siding and exterior gypsum board. Site inspections were done to determine cladding for the different blocks. Assumptions made with cladding include complete exterior coverage of cladding by level. There are slight variations to this in reality but the differences are deemed insignificant.
	2.1 Exterior Light Wood Frame		

	2.1.1 - 1st Floor (with brick facade)	The exterior walls on the ground floor are assumed to be completely cladded by modular brick. There are slight variations to height of cladding but this is not significant to the calculation of brick. The total length of the wall for each building type (A, B or C building floor plans) was calculated using a linear condition. A count condition was used to determine the number of doors and an area and count condition was used to determine the total area and number of windows on each level of wall. Within Athena, the maximum number of windows that a wall can contain is 100, so the total length of wall was divided up into several inputs within Athena depending on the number of windows in that wall type. For example, if the entire first floor A unit wall had 290 windows, there would be three inputs delineated by A.2.1.1a, A.2.1.1b, A.2.1.1c, with 90 windows each. The window frames were not specified within the architectural drawings so visual inspection was done to determine that standard aluminum frames with double pane standard glazing. - The polyethylene was specified as 4 mil but the closest option within Athena is 3 mil which is what was used. - 1" exterior insulation system specified (assumed and modeled as 1" expanded polystyrene) - R10 batt insulation (equivalent to and modeled as 3" fibreglass batt insulation)
	2.1.2 - 2nd and 3rd Floor (with wood facade)	The exterior walls were modeled as 2x4 lumber at 16" o.c. Athena adds additional wood to accomodate for windows and door reinforcing. The inputs for the 2nd and 3rd floors were combined to simplifiy inputs. If the ceiling hieghts differed between the second and third floors, the two heights added together and averaged to create one general input for both floors. - Wood bevel siding – pine (specific type not specified in drawings but assumed based on research on visual characteristics) - The polyethylene was specified as 4 mil but the closest option within Athena is 3 mil which is what was used. - 1" exterior insulation system specified (assumed and modeled as 1" expanded polystyrene) - R10 batt insulation (equivalent to and modeled as 3" fibreglass batt insulation) The exterior walls were modeled as 2x4 lumber at 16" o.c. Athena adds additional wood to accomodate for windows and door reinforcing based on number and size of window area specified in wall segment.
	2.1.2 - 2nd and 3rd Floor (with gypsum facade)	- Gypsum - Exterior gypsum board modeled as moisture resistant 1/2" gypsum board - The polyethylene was specified as 4 mil but the closest option within Athena is 3 mil which is what was used. - 1" exterior insulation system specified (assumed and modeled as 1" expanded polystyrene)

			- R10 batt insulation (equivalent to and modeled as 3" fibreglass batt insulation)
		2.2.1 - Interior Load Bearing Wall	The interior walls consist of load bearing, false and dividing walls. The interior load bearing and false walls were all assumed to be 2x4" construction with studs 16 o.c. and ½" regular gypsum sheathing on both sides of the wall. The load bearing and false walls were all assumed to have the same construction techniques to ease takeoffs because architectural drawings were used to complete the interior wall takeoffs. A slight overestimation of interior wall studs may result but is not expected to significantly skew the results of the analysis. This is the majority of interior walls are load bearing and the difference in materials is slight as false walls are framed at 24" o.c. as opposed to 16" o.c.. The dividing walls materials were calculated using the additional materials portion of Athena because of the unique framing attributes of the walls and the large total length (4415 ft). Doors were not specified and inputted in Athena as hollow core wood interior - assuming drywall on both sides - assuming avg wall height = 8.8' (26.4 ft tot. height / 3 floors) - 2 -2x6 plates on top and bottom of wall (4 - 2x6 per floor)
3 Roof			
	3.1 Wood Truss		
		3.1.1 Roof Main Span	The average span was determined in On-Center using the dimensioning tool. Several lengths would be taken of each unit and the average determined from the results. The total area of the roof was determined using an area condition and the corresponding length of the roof was determined by dividing the total area by the average span. The specified thickness for roof sheathing is 3/8" but the closest input to Athena is ½". A live load of 45 psf was assumed for the roof. The drawings specify that the attics are insulated with R20 fibreglass batt insulation with corresponds to 6" fibreglass batt insulation in the Athena model. Athena accepts inputs for insulation thickness and an insulation value of R20 batt was found using tables on the internet. The corresponding thickness of fibreglass batt in Athena was determined by correlating the insulations values of R20 batt to that of fibreglass batt insulation values per inch thickness.

		3.1.2 Roof Overhangs	The smaller roof overhangs are wood frame construction with similar materials used as the roof. The overhangs were calculated on a whole building scale instead of a per floor basis given the ease of input and the fact that the overhangs were uniform in construction and easily replicable over the different floors. The materials used in the overhang construction consist of specified ½" plywood decking, asphalt shingles, ½" gypsum board, 6 mil poly and 6" fibreglass batt insulation. A live load of 45 psf was assumed for the roof. The drawings specify that the attics are insulated with R20 fibreglass batt insulation with corresponds to 6" fibreglass batt insulation in the Athena model. The corresponding thickness of fibreglass batt in Athena was determined by correlating the insulations values of R20 batt to that of fibreglass batt insulation values per inch thickness.
	4.1 Wood I-Joist	**4.1.1 2nd Floor**	The Floors were modeled using the Modified Wood I-Joist option within Athena's Floor Assembly options. The floor joists were detailed within the architectural drawings and an average floor span was determined with the linear count tool within On-Center. The entire floor area was determined using the area tool within On-Center. Using the total floor area and average span length the floor width and span inputs were calculated by dividing the total floor area by average span. - Total Area (ft2) / Avg. Span (ft) = Floor Width (ft) - I-Joist Web Thickness dimensioned with On-Center and modeled as 1/2 in - Flange Type- MSR, assumed - Flange Size - 2.5 x 1.5 in - the average value of flange size for I-Joists was assumed - Web Type- Plywood, assumed - 1/2" gypsum board is included in the floor inputs to account for gypsum board on the lower floor's ceiling
		4.1.2 3rd Floor	The Floors were modeled using the Modified Wood I-Joist option within Athena's Floor Assembly options. The floor joists were detailed within the architectural drawings and an average floor span was determined with the linear count tool within On-Center. The entire floor area was determined using the area tool within On-Center. Using the total floor area and average span length the floor width and span inputs were calculated by dividing the total floor area by average span. - Total Area (ft2) / Avg. Span (ft) = Floor Width (ft) - I-Joist Web Thickness dimensioned with On-Center and modeled as 1/2 in - Flange Type- MSR, assumed - Flange Size - 2.5 x 1.5 in - the average value of flange size for I-Joists was assumed - Web Type- Plywood, assumed - 1/2" gypsum board is included in the floor inputs to account for gypsum board on the lower floor's ceiling
5 Extra Materials			
	5.1 Wood		

	A.5.1.1 - Stairs	The amount of wood material used for stairs was determined by counting the total number of steps for a building and then determining the average width of the steps. - The stringer was assumed to be 2x12" board - The riser was assumed to be 1/2" plywood and riser height assumed to be 8" and tread depth 9" - Example calculation for volume of wood per step = avg. width of step * thickness of tread * depth of tread + avg. riser vol. of wood per step =40in + 0.5in + 9in + 216 in^3 = 396 in^3
	5.1.2 - Dividing Walls	The dividing walls are used to separate different units from one another. For example, in a block of units, when a B-unit is specified beside a C-unit within the site layout, there is a common wall built between the two unit types. These walls are constructed differently than typical interior walls. For example, the walls are framed on a double 2x6 base board and header with 2x4 studs in T configurations spaced every 24" on center. The sheathing material is assumed to be standard ½" regular gypsum which is typical in house framing. The ½" regular gypsum is also included in additional materials (total area = 77700 sqft). Wall heights vary slightly between units and floors and a standard height of 8'8" is used in the calculations. - Example calculation to determine volume of wood in dividing walls: 2- 2x4 spaced 24"o.c. . =(avg. wall height*(2x4 vol. wood per 1 ft)*4 ft)+((2x6 vol per 1 ft length)*4 boards per section* 4' length) =(8.3*(1.5*3.5*12)*4)+((1.5*5.5*12)*4*4) = 2091.6 + 1584 = 3675.6 ft^3 - calculated average wall height per floor as 8.8' (26.4' total height / 3 floors = 8.8') - 2- 2x6 plates on top and bottom of wall (4-2x6 per floor) - Example calculations to determine total volume of wood for dividing walls: =Total wood per foot used for dividing walls = (2.13 ft^3 per 4' length)*(1471 ft)*(3 floors)/(4) = 2346.7 ft^3 per foot = Total volume wood for dividing walls (mfbm) = 2346.7 ft^3 *(0.012) = 28.16 mfbm
5.2 Concrete	**5.2.1 Concrete Floor Topping**	Concrete floor topping was specified for the third and fourth floors as 0.125 ft thick. The total floor area on all buildings was determined using the area tool in On-Center and the specified thickness was used to determine total additional concrete for floor topping.
	5.2.2 Block Walls	Concrete block walls are used twice in the Fairview Residences as firewalls in the two longest sections. The walls extend from ground level to the third floor and it is assumed that standard 8x8x16" blocks are used. - Total length of block walls = 100 ft -Total height of block walls = 26.4 ft - Number of rows in block wall = 26.4 ft / 0.67 ft = 39.4 ft ~ 39 blocks high =Total number of blocks = Tot. Length / Length of Block * Number of Rows = (100 ft / 1.33)*39 = 2932 blocks - Volume of Grout (assuming 3/8" thickness) = Number of Rows * Thickness of Grout * Grout area = 39 * 0.67 ft2 * 0.0 3125 ft = 0.825 ft 3 = 0.0306 yards

		5.2.3 Concrete Footing - Slab on Grade	Concrete slab on grade floors were used in the V,W,X and Y blocks. The additional concrete used for slab on grade footings was determined by using the linear condition in On-Center to first determine the total length of slab perimeter. The dimensions of the footings were assumed to be 10x10" and total length of footings is 3503 ft.
		5.2.4 Concrete - Foundation - Slab on Grade	The concrete foundation slab on grade was specified as 6" thick. The area of each unit was determined using On-Center area tool and the volume of concrete was determined using the specified thickness of the slab. The total volume of concrete was then determined using the total volume per building unit and the total number of units included in the V,W,X and Y blocks. - Total Area of Unit = 2750 ft^2 -Thickness of Concrete Slab = 6" - Volume of Concrete per unit = 2750 ft^2 * 0.5 ft = 1375 ft^3
	5.3 Gypsum		
		5.3.1 Diving Walls	The area of the dividing walls was calclulated by assuming a height of 26.4' for all three floors and then using a linear condition to determine the total length of dividing wall. To determine the total amount of gypsum used to sheath the dividing walls, the area determined was multiplied by 2 to account for both sides of the shared wall.
	5.4 Steel		
		5.4.1 Reinforcing Steel	The amount of reinforcing steel to include in extra materials for the slab on grade concrete was determined by modelling an equivalent section of slab on grade concrete and determining the amount of steel that was included in that volume of concrete. The amount of reinforcing steel necessary was adjusted to accomodate the total area of slab on grade concrete.