H.R. MacMillan, University of British Columbia

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University of British Columbia

CIVL 498C

November 26, 2013

PROVISIO

This study has been completed by undergraduate students as part of their coursework at the University of British Columbia (UBC) and is also a contribution to a larger effort – the UBC LCA Project – which aims to support the development of the field of life cycle assessment (LCA).

The information and findings contained in this report have not been through a full critical review and should be considered preliminary.

If further information is required, please contact the course instructor Rob Sianchuk at rob.sianchuk@gmail.com

LIFE CYCLE ASSESSMENT

H.R. MacMillan, University of British Columbia

Jericho Velarde

[redacted]

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1.0 General Information on the Assessment

Purpose of the assessment

The Life Cycle Analysis (LCA) of the H.R. MacMillan building is done in order to assess the environmental impact of the design of the building. The main intent of this study is to update the previous assessment to the most current standards and comparatively see the impacts of its design as oppose to other building in and around the University of British Columbia (UBC) area.
An exemplary application of this study is to use it as a benchmark for future designs of academic buildings in UBC and possibly in North America. Another application is for the future improvements and upgrades of the H.R. MacMillan building, in which this study can be used to assess different materials that can be improved in order to minimize the overall environmental impact of the building.

The intended audience of this LCA study are for those involved in building related policy making at UBC, like the Sustainability Office, who are the once that are mainly involved in creating frameworks and policies for sustainable development on campus. Other possible audiences include organizations such as the government, engineers, architects, contractors, and potentially anyone that is involved in the design stage of a building who may want to perform similar LCA studies within their organizations and comparatively show their performance against buildings on the UBC campus.

Identification of building

The H.R. MacMillan is located on the UBC campus at 2357 Main Mall, Vancouver, BC. It was built in 1967, originally known as the Forestry Agriculture building. The three-storey plus one ground floor building measuring at roughly 12254 m^2, serves as an academic research building that features approximately 11 classrooms, 43 labs, and 65 offices. It cost roughly $4.5 million to build was designed by McCarter Nairne & Associates, a Vancouver based architectural and engineering firm. (1)

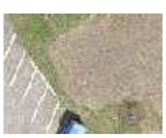

Figure 1 - Aerial View of the H.R. MacMillan Building

(1) http://www.library.ubc.ca/archives/bldgs/macmillan.htm

Other Assessment Information

The **Table 1** below proves a summary of assessment information.

Table 1 – Summary of Assessment Information

Client for Assessment	Completed as coursework in Civil Engineering technical elective course at the University of British Columbia.
Name and qualification of the assessor	Jericho Velarde and Integrated Engineering Student and Ivan Yip-Hang Tang a Civil Engineering graduate from UBC
Impact Assessment method	Athena Impact Estimator 4.2
Point of Assessment	46 years after the building's construction
Period of Validity	5 years.
Date of Assessment	Completed in November 2013.
Verifier	Student work, study not verified.

2.0 General Information on the Object of Assessment

Functional Equivalent

Functional units are defined as a quantified performance of a product system for use as a reference unit. In other words, it is the measure of the performance of everything that went into the construction of the H.R. MacMillan building, including transportation, broken down into its impacts per meter squared. This allows as a reference to which all the inputs and outputs can be related and compared. For example, this breaks down the environmental impacts of the concrete used for slab on grade as well as the concrete used for the columns, even though they have different functions and are constructed quite differently. This is important because this study will be used as a comparative assertion and as well as to aid in setting a benchmark for future educational buildings, and breaking everything down to functional units will allow comparison between similar buildings as described in **Table 2**.

Table 2 - Functional Equivalent Definition

Aspect of Object of Assessment	Description
Building Type	Educational & Institutional building
Technical and functional requirements	Codes: CSA CAN3-G40.21-MB1 (Steel and Hollow structural materials), ASTM A325-M79 (Nuts, Washers and Bolts), CISC/CMPA Standard (Coat), NLGA Standard (Sawn Timber), 1998 British Columbia Building Code/ functional: Lab, Store room, Library, Office, Museum, Vault, research room, Lavatory, Locker room, Lecture room, classes

Pattern of use	H.R. MacMillan is an academic research building that is used for multiple purposes such as an office for multiple staff, lecture rooms for students, research space for grad students and researchers and study space for students. It also houses a small library on the top floor and a café at the bottom floor.
Required service life	60 years

Reference Study Period

The required service life of the H.R. MacMillan building, like any other educational institution, is roughly 60 years. However, the reference study period is only 1 year for this assessment. This is because for this study we are only looking at the impacts of the building due to raw material extraction until the end of construction. This means that we are looking at the impacts of everything that went into the building from manufacturing, transportation, construction, up until the building was ready to be opened. Therefore, impacts from the building's use stage, such as servicing and replacing parts, and as well as the end of life, which includes disposal of materials, are not included because this study is strictly being used for comparison of materials used in its construction. It is also very difficult to account for the use stage of the H.R. MacMillan building because it is very old and it has been serviced and parts have been replaced since its initial construction. Hence, in order to keep consistency in the overall study, in which the H.R. MacMillan building is a part of, the decided reference study period for all the buildings is set to 1 year.

Object of Assessment Scope

The object of assessment scope encompasses the entirety of the building from its foundation to the external works within the area of the building's site. **Table 3** below shows a detailed description of the general characteristics of the H.R. MacMillan building.

Table 3 – Building Characteristics

Building System	Specific characteristics for H.R. MacMillan
Foundation	Concrete slab on grade with polyethylene vapour barrier as well as concrete footings
Structure	Concrete beams and columns, and concrete blocks supporting concrete tees; Penthouse: steel WF beams and columns
Floors	First, Second, and Third Floors: Concrete tees with topping
Exterior Walls	Ground: Cast in place walls, some with modular brick cladding, rigid insulation; First, Second, and Third Floors: concrete block walls with modular brick cladding, rigid insulation and windows, concrete cast in place walls with modular brick cladding and rigid insulation; Penthouse: modular brick cladding
Interior Walls	Ground: concrete block walls; First, Second, and Third Floors: concrete block walls, some with plaster or modular brick cladding, and aluminum framed curtain walls
Windows	Most windows standard single glazed, either aluminum or steel frames, a few windows double glazed

Roof	Main Roof: Suspended slab with rigid insulation, some with plaster; Penthouse Roof: Steel decking

The Canadian Institute of Quantity Surveyors (CIQS) established a standardize list of elements that enables cost analyses and control on building projects. A modified version of CIQS Level 3 Elements was used as shown in **Table 4.** This was done in order to simplify and encompass everything that is involved in the structure and envelope of the H.R. MacMillan building and to easily compare all the elements to other institutional building in the UBC area.

Table 4 - Building Definition

CIVL 498C Level 3 Elements	Description	Quantity (Amount)	Units
A11 Foundations	Total area of the slab-on-grade.	3292	m2
A21 Lowest Floor Construction	Total area of the slab-on-grade.	3292	m2
A22 Upper Floor Construction	Sum of the total area of all upper floor(s) measured from the outside face of the exterior walls.	8962	m2
A23 Roof Construction	Sum of total area of the roof(s) measured from the outside	2987	m2

	face of the exterior walls.		
A31 Walls Below Grade	Sum of total surface area of the exterior walls below grade.	2515	m2
A32 Walls Above Grade	Sum of total surface area of the exterior walls above grade.	4118	m2
B11 Partitions	Sum of total surface area of the interior walls.	13664	m2

3.0 Statement of Boundaries and Scenarios Used in the Assessment

System Boundary

The building life cycle modules that are included in this study of the H.R. MacMillan building are the product stage and construction process stage. The product stage includes everything that goes into the building from the raw material extraction to the construction stage of the building, which includes transportation and manufacturing. The construction process stage includes impacts due to the transportation from the manufacturer and the construction process. The construction process varies greatly on what the manufactured materials are being used for and is described in greater detail below.

Product Stage

The product stage is what is known as 'cradle to gate' which are reference flows for the construction stage of the building. For H.R. MacMillan this includes the raw materials extracted, transported and manufactured for its construction.

The amount of raw resource used in the production of a building is reported in kilograms (kg), which is also how the waste from the manufacture stage is presented. However, since it can be seen that dissimilar products such as timber and concrete cannot be easily compared in terms of their weight, a weighting factor is then therefore applied. The weighting index used by the Athena Life Cycle Inventory (LCI) database is gathered through a survey of a number of resource extraction and environmental specialists across North America. This information is then used by the Impact Estimator (IE) to apply to the raw resource used which is then summed up and reported as an overall weight in kilograms. This weight reported is but a mere reflection of the opinions of the surveyed experts and must therefore be taken as such.

The transportation aspect of the product stage is dependent on the location stated in the inputs of the IE. Athena's database is regionally sensitive and takes into account transportation of products that are manufactured only in certain parts of North America, like lumber. These cause the greatest impacts in terms of transportation dependent on location, because specialty products may need to travel further in order to get to its destination. However, since H.R. MacMillan consists of mostly concrete and concrete is easily produced locally and could also be manufactured on site, the transportation impact of concrete is not greatly affected by location.

Construction Stage

The construction stage of the life cycle includes all the processes that transpire from the factory gate until the completion of the construction work. This includes two main processes, the transportation from factory to site and the construction of the building.

As stated before, the transportation impact is greatly dependent on the location set in the inputs of the IE. However, as previously stated, since the H.R. MacMillan building is predominantly concrete based, the location does not play as big of a factor in the transportation stage. However, the transportation of concrete still does deal a great impact on the overall life cycle of the building.

The construction process of the building includes provision for installation and on site transformation of construction parts. The installation of the products varies in terms of their intended purpose. The IE takes into account the height of the column and its overall dimensions. However, the IE does have limitations and therefore approximate dimensions must be used in order to approximate the impacts due to construction. These materials are then put into extra materials and are based on their overall volume rather than actual dimensions. This may cause some problems in calculating overall impacts because for example, the construction of a concrete column is greatly dependent on height and by only inputting the overall volume of concrete used the energy it takes to build a column up and the resources used would not be taken into consideration.

4.0 Environmental Data

Data Sources

The Athena LCI Database was developed by the Athena Institute who has invested a large amount of time and resources in the development of the database. They conduct independent research to expand the database and work with industry specialists to conduct a thorough LCI. The Athena Institute also take into account research for things other than building products, such as energy use, transportation, construction and demolition processes. Although, for this study, we do not account for demolition processes, it would still be a great tool to have when looking at the end of life process of the life cycle.

Data Adjustments and Substitutions

There were very few material type and property inaccuracies found in the Impact Estimator model for the H.R. MacMillan building. The first, with the lower impact, is the live loads for the columns. Since IE only has three options available for the live load; 45 psf, 75 psf, and 100 psf, the loads for labs and offices that was used was 100 psf instead of their specified 120 psf, and 50 psf respectively. Furthermore, the loads used for class rooms, which was specified for 60 psf, was 60 psf in order to balance the overall estimate. The second inaccuracy, and with a much greater impact, is the concrete precast tees used for the flooring system. The precast tees used in the H.R. MacMillan building are single, however the IE only allowed for double tees. This does not cause too much of a discrepancy though because the dimensions used allocated for the inaccuracy. No other LCA information was found about single precast tees and so it was difficult to see the improvements of using it in the product and construction stages.

Data Quality

The quality of data used in the study of the H.R. MacMillan building was sufficient in satisfying the stated requirements. There were some uncertainty with the data as the drawings were old and hand drawn and was difficult to read. In these cases a site visit was done in order to accurately measure the desired dimensions whenever possible, otherwise assumptions where used. The inaccuracies of the model lay heavily on the dimension limitations set by the Impact Estimator. An equivalent volume or surface area was used in order to compensate for this. However, there are cases where these assumptions would be insufficient due to the different limitations of constructing and installing different dimensions. The temporal uncertainty raised in this study is the reference study period. This is because for the model used for the H.R. MacMillan building, the assumption for the reference study period of the building was set at 1 year, in order to eliminate the impacts due to the use stage. Spatial uncertainty is the difference between what is in the database and what is found in the actual building; in this case it is the same as the data and model uncertainties. The variability between the objects and sources is also a concern. An example of this is the concrete fly ash percentage which was not stated in the drawings but the average was assumed for the model. However, the overall quality of the data was more than sufficient for this study's application.

5.0 List of Indicators Used for Assessment and Expression of Results

The six impact categories that are determined in this project are global warming potential, acidification potential, human heal respiratory effects potential, eutrophication potential, ozone depletion potential and smog potential. These indicators are used in order to determine the severity of the impacts of the construction of the H.R. MacMillan building as oppose to other buildings in the UBC area.

Global warming potential

Global warming potential is the measure of the potential of contribution of a material or products towards global warming through greenhouse effect, which is measured relative to the effect of carbon dioxide (CO_2). The units are reported in equivalent kilograms or tonnes of CO_2. Other chemicals also contribute towards global warming, but they are all reported in terms of their assigned multiple of the CO_2 equivalent. The temporal effects of chemicals in terms of global warming are uncertain due to their unknown reactivity and stability at atmospheric environment. Greenhouse gas emissions are primarily produced when fuels are combusted, but some products also produce emissions during manufacture or processing. The Athena Impact Estimator uses a detailed life cycle modelling technique that captures all relevant emissions, including any released during processing. Uncertainty arises in modelling greenhouse gas emissions and global warming potential as it is difficult to account for emissions produced during complex processes, such as those that transpire during the manufacturing stage and variations in the construction stage.

Acidification potential

Acidification potential is the measure of acid depositions, which have negative impacts towards the natural ecosystem and man-made environment. The acidification potential of the emissions due to agriculture and fossil fuel combustion are calculated based on their H+ equivalence per unit mass. High concentration of NO_X and SO_2 are known to produce adverse effects on the life of buildings and the environment. However, much uncertainty is present in this field as it is not yet widely understood.

Human health respiratory effects potential

Human health respiratory effects potential reports the effects of particulate matter have on human health, particularly the respiratory system. Particulates have a serious impact on human health and cause respiratory deterioration and diseases such as asthma and bronchitis. Therefore this effect is heavily reliant on the transportation of the materials and the emissions during the construction and manufacturing stage of the building. This impact category is reported in kg PM10eq.

Eutrophication potential

Eutrophication is the process increasing the nutrients in previously nutrient scarce surface water bodies and is measured relative to nitrogen equivalents. The addition of nutrients to a body of water can leads to an increase in photosynthetic aquatic plant life like algae. The new growth can dominate and devastate natural species and cause other consequences such as death to fish and foul odour. This may be caused by the waste by product of the building and its improper disposal. Eutrophication potential is reported in kg N eq.

Ozone depletion potential

Ozone depletion potential is the measure of impacts related to the reduction of the ozone layer. This is the protective layer in the atmosphere that absorbs a large majority of the sun’s ultraviolet light and protects the earth’s inhabitants. The depletion is caused by emissions of ozone depleting substances such as CFCs, HFCs, and halons. The ozone depletion potential of each of a chemical or substance is measured relative to CFC-11, and is reported in kg CFC-11 eq.

Smog potential

Smog is a type of air pollution, a product of industrial and/or transportation emissions being trapped close below atmospheric level where it can reacts under certain atmospheric condition with sunlight. Smog is a serious issue affecting human health in many cities most commonly in cities with sunny, warm, dry climates and a large amount of vehicles. Industries release nitrogen oxides (NOx) and other man-made products release volatile organic compounds (VOCs). Smog potential is reported in kg NOx eq.

6.0 Model Development

The H.R. MacMillan building was previously modeled with the software program OnScreen Takeoff, which was first used to measure, count and inventory the building elements. The measurements were then used to create a model building in the Athena Impact Estimator software in which results were presented, which can be found in Annex A. The inputs and assumptions used can be found in Annex D, which addresses issues and limitations of the programs and how they were mitigated. The inputs were also sorted in a modified CIQS Level 3 method in which they were separated in terms of Foundation, Lowest Floor Construction, Upper Floor Construction, Roof Construction, Walls Below Grade, Walls Above Grade, and Partition.

The Foundation section (A11) included everything that went into the construction of the foundation. The unit area was calculated by the slab on grade (SOG) of the building. The bill of materials is shown in **Table 5** below.

Table 5 - Foundation Bill of Materials

Material	Quantity	Unit
5/8" Regular Gypsum Board	780.3188	m2
6 mil Polyethylene	3492.0754	m2
Concrete 20 MPa (flyash av)	8337.0593	m3
Joint Compound	0.7788	Tonnes
Nails	0.0073	Tonnes
Paper Tape	0.0089	Tonnes
Rebar, Rod, Light Sections	20.4612	Tonnes
Welded Wire Mesh / Ladder Wire	3.4939	Tonnes

Similar to the foundation, the unit area of the Lowest Floor Construction (A21) was also calculated by the SOG of the building. The Lowest Floor Construction included the columns that held up the lowest floor, along with the overall concrete used in the construction of the floor. The bill of materials for the lowest floor constructions is shown in **Table 6** below.

Table 6 – Lowest Floor Construction Bill of Materials

Material	Quantity	Unit
6 mil Polyethylene	3492.0754	m2
Concrete 20 MPa (flyash av)	354.7633	m3
Welded Wire Mesh / Ladder Wire	3.0534	Tonnes

The Upper Floor Construction (A22) included everything that was used in the construction of the upper floors of the H.R. MacMillan building. This includes the columns that supports to floors but does not include the columns that support the roof. The unit area is calculated by the overall area of the 1st, 2nd and 3rd floor of the H.R. MacMillan building. The bill of materials for the upper floor constructions is shown in **Table 7** below.

Table 7 – Upper Floor Construction Bill of Materials

Material	Quantity	Unit
Concrete 20 MPa (flyash av)	136.6785	m3
Concrete 30 MPa (flyash av)	2740.1463	m3
Metric Modular (Modular) Brick	3411.156	m2
Mortar	8.257	m3
Precast Concrete	4024.1482	m3
Rebar, Rod, Light Sections	281.5845	Tonnes
Welded Wire Mesh / Ladder Wire	47.9697	Tonnes

The Roof Constructions (A23) constitutes for the unit area of the roof and the materials that was used in the construction of the roof. Thus, like the other floor constructions, this includes the columns that support the roof and the cement that is in the roof. The bill of materials for the roof construction is shown in **Table 8** below.

Table 8 – Roof Construction Bill of Materials

Material	Quantity	Unit
24 Ga. Steel Roof (Commercial)	1455.702	m2
Concrete 20 MPa (flyash av)	1933.5808	m3
Concrete 30 MPa (flyash av)	201.2154	m3
Extruded Polystyrene	7399.003	m2 (25mm)
Galvanized Decking	11.2274	Tonnes
Modified Bitumen membrane	2016.006	kg
Nails	0.4393	Tonnes
Open Web Joists	4.5681	Tonnes
Rebar, Rod, Light Sections	139.025	Tonnes
Screws Nuts & Bolts	0.5734	Tonnes
Solvent Based Alkyd Paint	481.3118	L
Wide Flange Sections	11.0153	Tonnes

The Walls Below Grade (A31) includes all the exterior walls that are found below grade. The H.R. MacMillan building uses mostly bricks for all exterior walls, and the walls below grade are found on the ground floor. The bill of materials for the walls below grade is shown in **Table 9** below.

Table 9 – Walls Below Grade Bill of Materials

Material	Quantity	Unit
5/8" Regular Gypsum Board	1100.0876	m2
Aluminum	28.9986	Tonnes
Cold Rolled Sheet	0.0667	Tonnes
Concrete 20 MPa (flyash av)	279.3859	m3
Double Glazed No Coating Air	3137.7844	m2
EPDM membrane (black, 60 mil)	1937.7697	kg
Expanded Polystyrene	26.04	m2 (25mm)
Extruded Polystyrene	1353.7107	m2 (25mm)
Galvanized Sheet	0.4953	Tonnes
Glazing Panel	1.3182	Tonnes
Joint Compound	1.0979	Tonnes
Metric Modular (Modular) Brick	346.846	m2

Mortar	9.1112	m3
Nails	1.7783	Tonnes
Paper Tape	0.0126	Tonnes
Rebar, Rod, Light Sections	7.3219	Tonnes
Solvent Based Alkyd Paint	2.3582	L

The Walls Above Grade (A32) are the exterior walls in floors 1, 2 and 3. They consist of mostly bricks and the overall area is the summation of the area of the walls in all 3 floors. The bill of materials for the walls above grade is shown in **Table 10** below.

Table 10 – Walls Above Grade Bill of Materials

Material	Quantity	Unit
5/8" Regular Gypsum Board	2472.7412	m2
Aluminum	42.3338	Tonnes
Cold Rolled Sheet	0.7412	Tonnes
Concrete 20 MPa (flyash av)	131.2258	m3
Concrete Blocks	38743.0471	Blocks
Double Glazed No Coating Air	1627.8475	m2
EPDM membrane (black, 60 mil)	2895.5896	kg
Extruded Polystyrene	3355.6671	m2 (25mm)
Joint Compound	2.4678	Tonnes
Metric Modular (Modular) Brick	3852.75	m2
Mortar	224.7454	m3
Nails	2.6448	Tonnes
Paper Tape	0.0283	Tonnes
Rebar, Rod, Light Sections	21.3585	Tonnes

The Partition (B11) allocated for all the interior walls in the H.R. MacMillan building. This contributes for the most amount of area covered and is mostly made out of concrete. The bill of materials for partitions is shown in **Table 11** below.

Table 11 – Partitions Bill of Materials

Material	Quantity	Unit
5/8" Regular Gypsum Board	4967.4092	m2
Aluminum	10.2935	Tonnes
Cold Rolled Sheet	0.226	Tonnes
Concrete 20 MPa (flyash av)	6.5286	m3
Concrete Blocks	159277.4452	Blocks
EPDM membrane (black, 60 mil)	375.6929	kg
Galvanized Sheet	0.3879	Tonnes
Glazing Panel	40.2172	Tonnes
Joint Compound	4.9576	Tonnes
Metric Modular (Modular) Brick	1174.9633	m2
Mortar	537.5698	m3
Nails	1.2481	Tonnes
Paper Tape	0.0569	Tonnes
Rebar, Rod, Light Sections	73.2312	Tonnes
Screws Nuts & Bolts	0.2465	Tonnes
Small Dimension Softwood Lumber, kiln-dried	38.4134	m3
Water Based Latex Paint	346.0648	L

7.0 Communication of Assessment Results

Life Cycle Results

The fossil fuel consumption of the H.R. MacMillan building is shown in **Figure 2** below. The graph is broken down into the modified CIQS Level 3 section. The benchmark is further addressed in Annex A. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

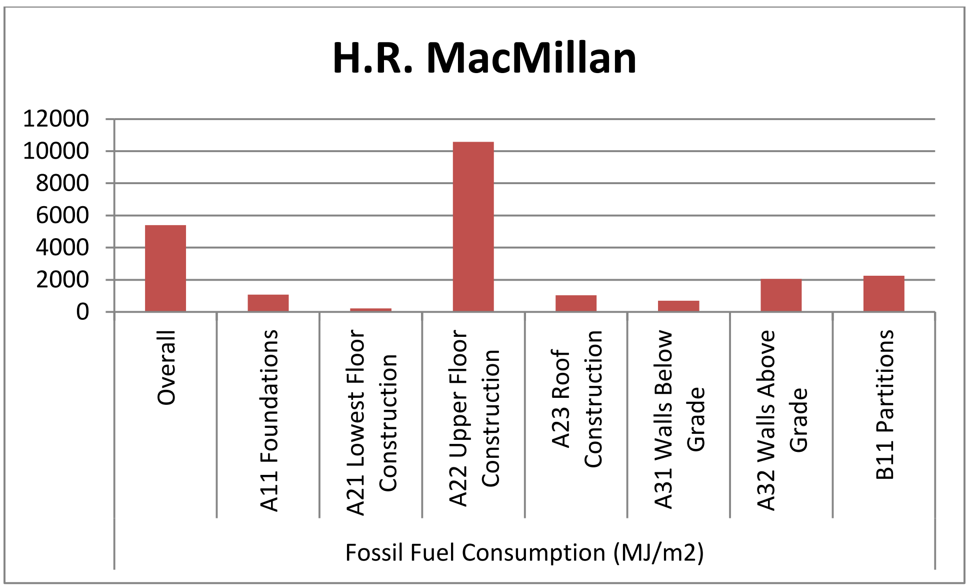

Figure 2 - Fossil Fuel Consumption (MJ/m2) of H.R. MacMillan

The global warming potential of the H.R. MacMillan building is shown in **Figure 3** below. The graph is broken down into the modified CIQS Level 3 section. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

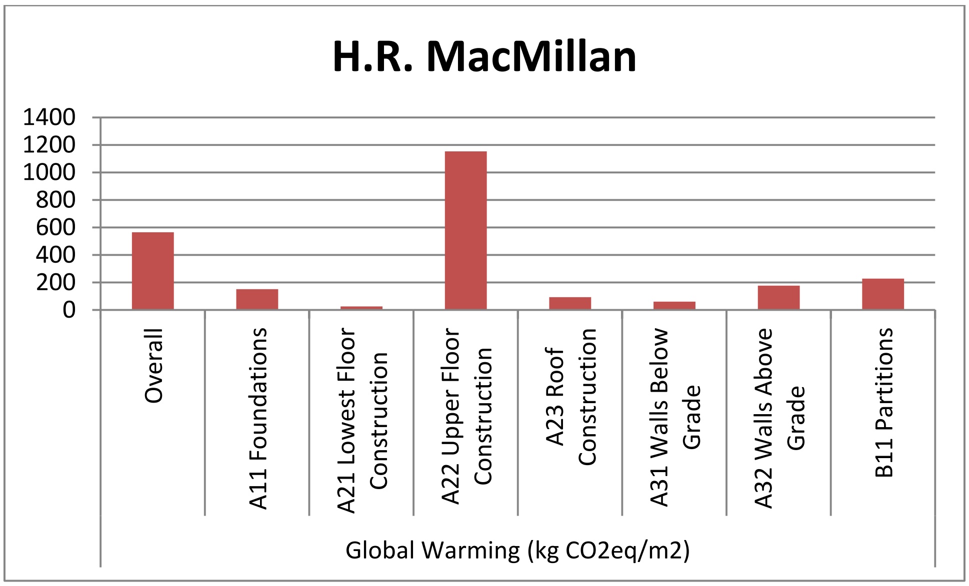

Figure 3 - Global Warming (kg CO2eq/m2) of H.R. MacMillan

The acidification potential of the H.R. MacMillan building is shown in **Figure 4** below. The graph is broken down into the modified CIQS Level 3 section. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

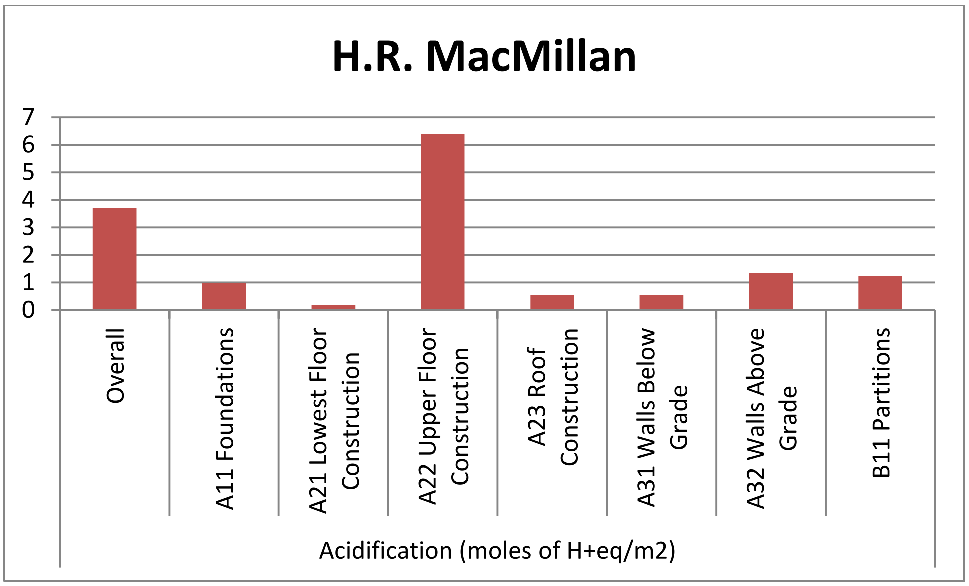

Figure 4 - Acidification (moles of H+eq/m2) of H.R. MacMillan

The human health respiratory effects potential of the H.R. MacMillan building is shown in **Figure 5** below. The graph is broken down into the modified CIQS Level 3 section. The benchmark is further addressed in Annex A. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

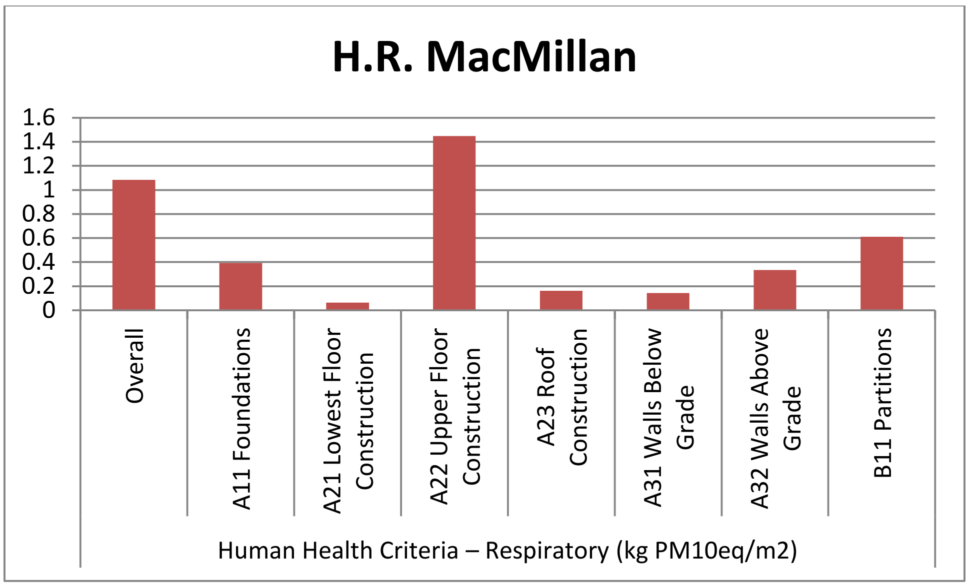

Figure 5 - Human Health Criteria – Respiratory (kg PM10eq/m2) of H.R. MacMillan

The eutrophication potential of the H.R. MacMillan building is shown in **Figure 6** below. The graph is broken down into the modified CIQS Level 3 section. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

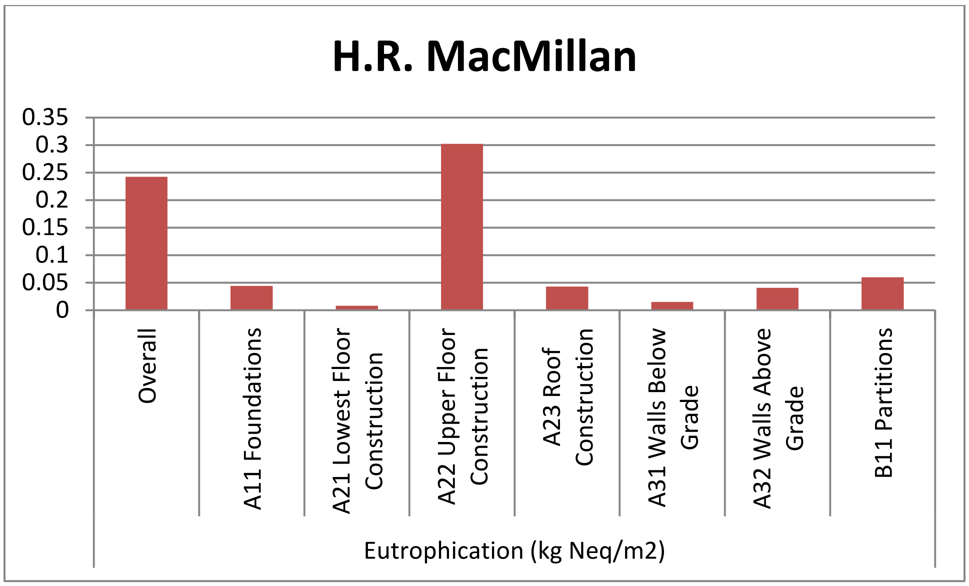

Figure 6 - Eutrophication (kg Neq/m2) of H.R. MacMillan

The ozone layer depletion potential of the H.R. MacMillan building is shown in **Figure 7** below. The graph is broken down into the modified CIQS Level 3 section. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

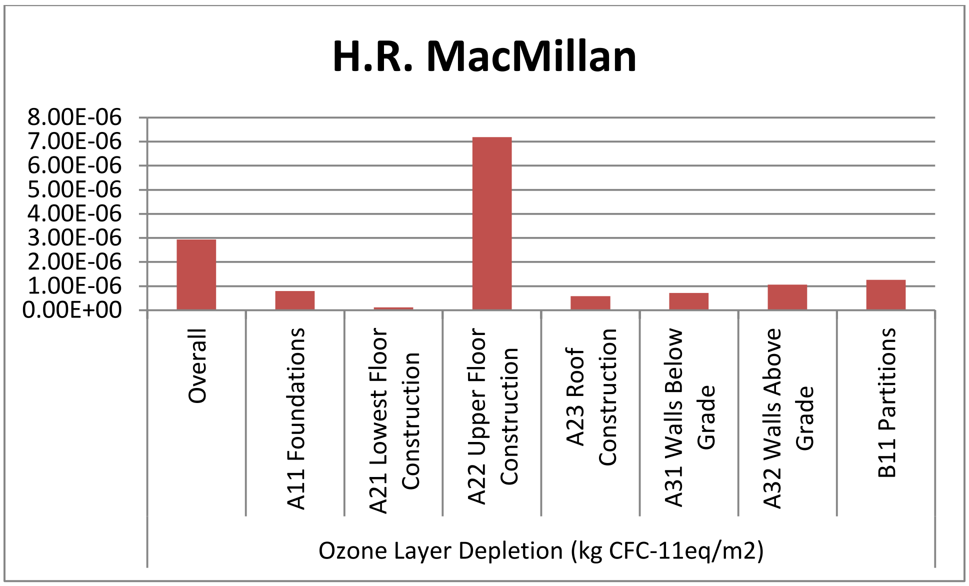

Figure 7 - Ozone Layer Depletion (kg CFC-11eq/m2) of H.R. MacMillan

The smog potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 8** below. The graph is broken down into the modified CIQS Level 3 section. The benchmark is further addressed in Annex A. There is a major difference between the impacts per unit area in the upper floor construction of the H.R. MacMillan building and the average, which may be due to miscalculation of the overall area.

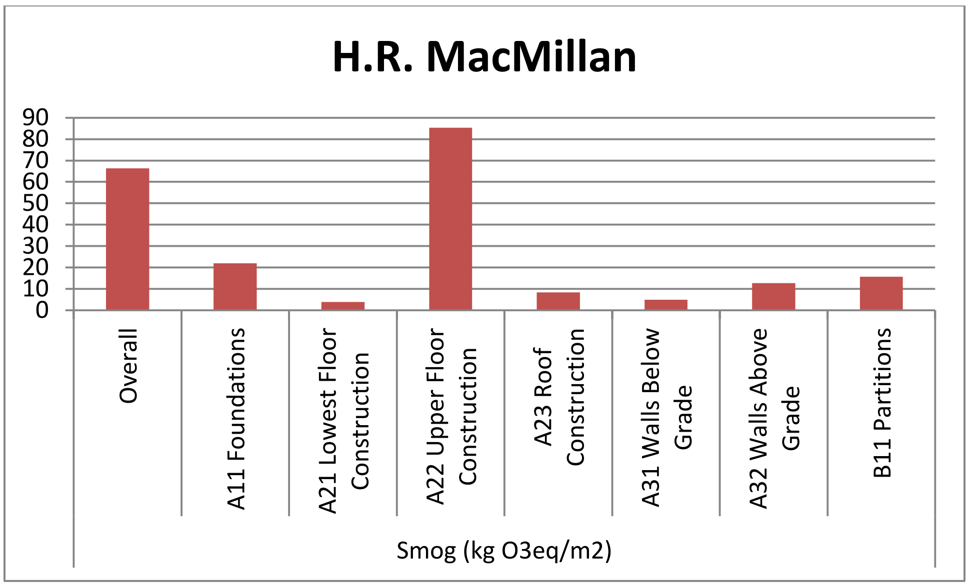

Figure 8 - Smog (kg O3eq/m2) of H.R. MacMillan

Annex A - Interpretation of Assessment Results

Benchmark Development

The development of a benchmark is very necessary in LCA. It allows for comparison of results of future LCA studies. The benchmark allows for better interpretation of the overall result and also sets a standard for what constitutes as a sustainable building.

UBC Academic Building Benchmark

The fossil fuel consumption of the H.R. MacMillan building compared to the benchmark is shown in **Figure 9** below. As represented by the graph, the H.R. MacMillan building consumes less fossil fuel than the benchmark.

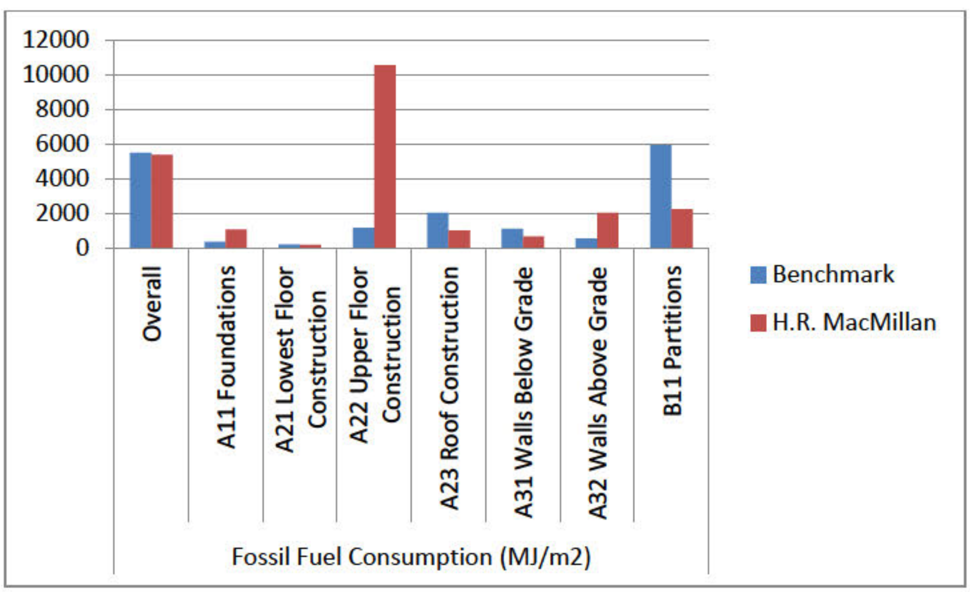

Figure 9 - Fossil Fuel Consumption (MJ/m2) of H.R. MacMillan and Benchmark

The global warming potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 10** below. As represented by the graph, the H.R. MacMillan building has a higher global warming potential than the benchmark.

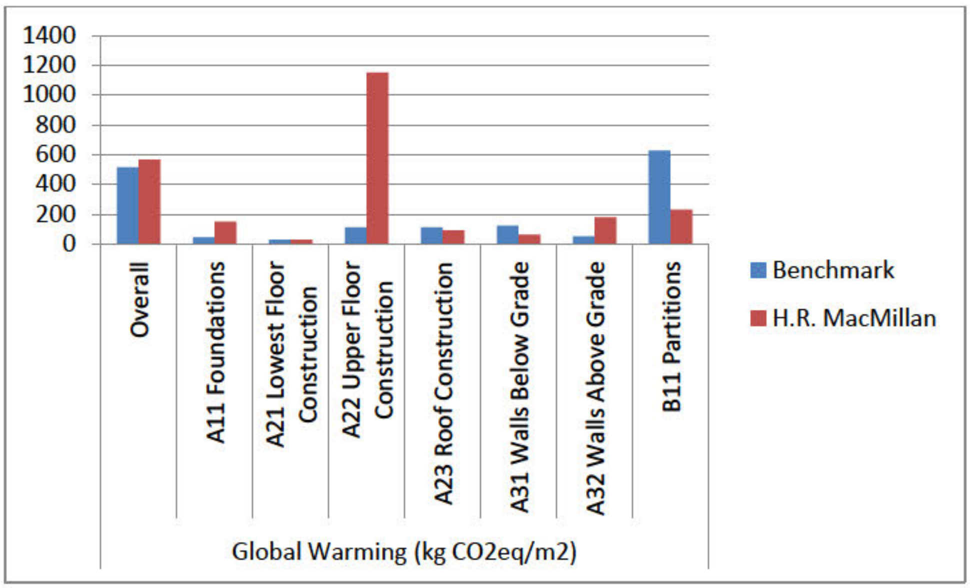

Figure 10 - Global Warming (kg CO2eq/m2) of H.R. MacMillan and Benchmark

The acidification potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 11** below. As represented by the graph, the H.R. MacMillan building has almost an equivalent acidification potential as the benchmark.

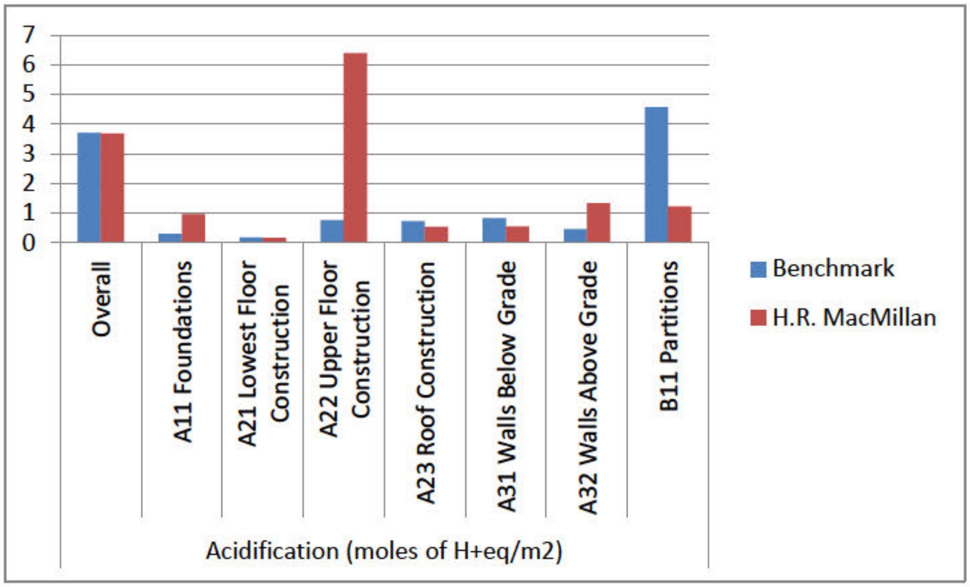

Figure 11 - Acidification (moles of H+eq/m2) of H.R. MacMillan and Benchmark

The human health respiratory effects potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 12** below. As represented by the graph, the H.R. MacMillan building has a lower human health respiratory effects potential than the benchmark.

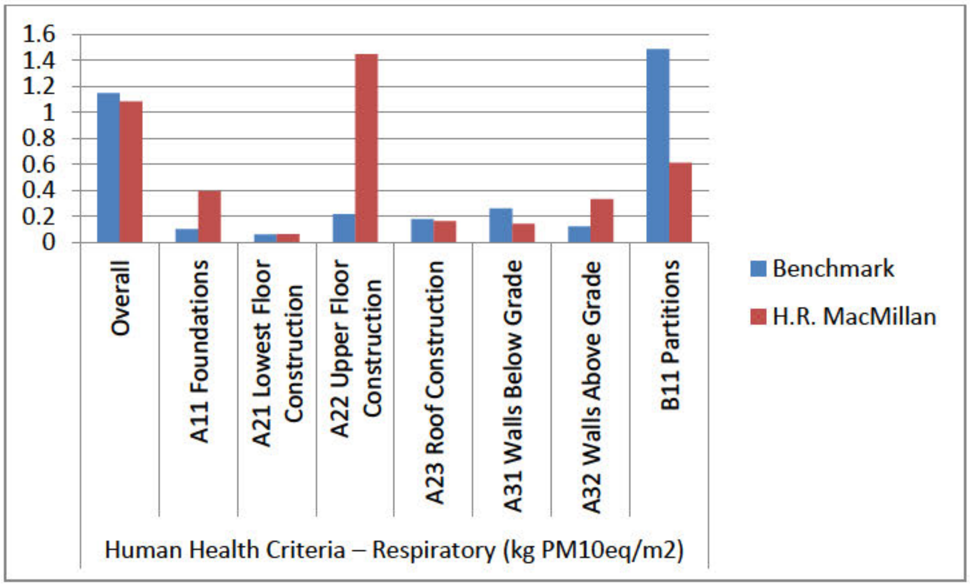

Figure 12 - Human Health Criteria – Respiratory (kg PM10eq/m2) of H.R. MacMillan and Benchmark

The eutrophication potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 13** below. As represented by the graph, the H.R. MacMillan building has a higher eutrophication potential than the benchmark.

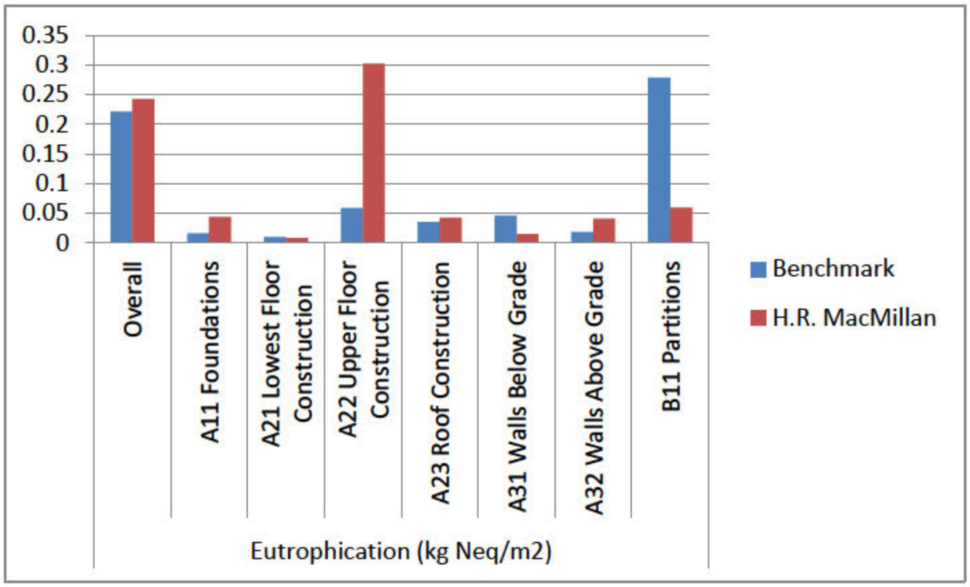

Figure 13 - Eutrophication (kg Neq/m2) of H.R. MacMillan and Benchmark

The ozone layer depletion potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 14** below. As represented by the graph, the H.R. MacMillan building has a higher ozone layer depletion potential than the benchmark.

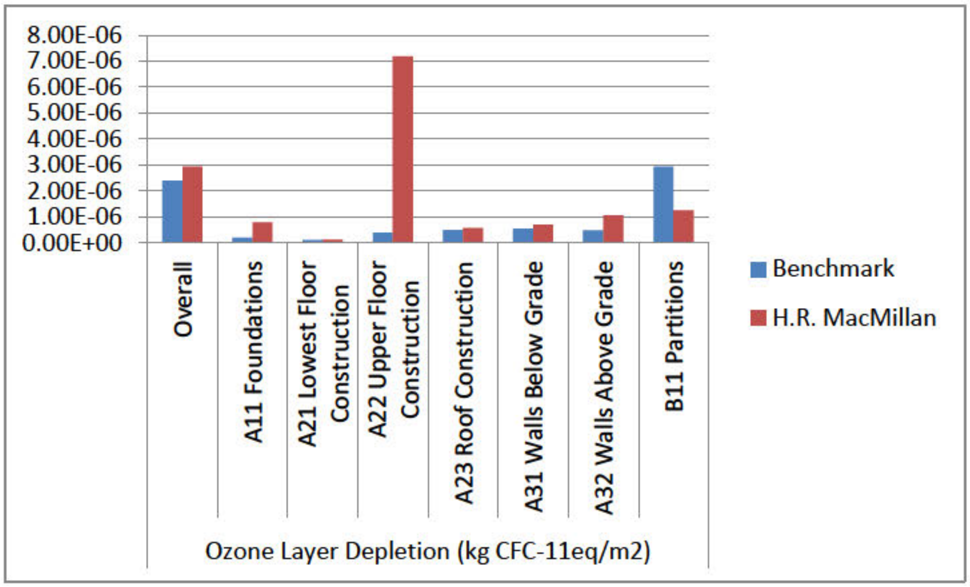

Figure 14 - Ozone Layer Depletion (kg CFC-11eq/m2) of H.R. MacMillan and Benchmark

The smog potential of the H.R. MacMillan building compared to the benchmark is shown in **Figure 15** below. The graph is broken down into the modified CIQS Level 3 section. As represented by the graph, the H.R. MacMillan building has a smog potential than the benchmark.

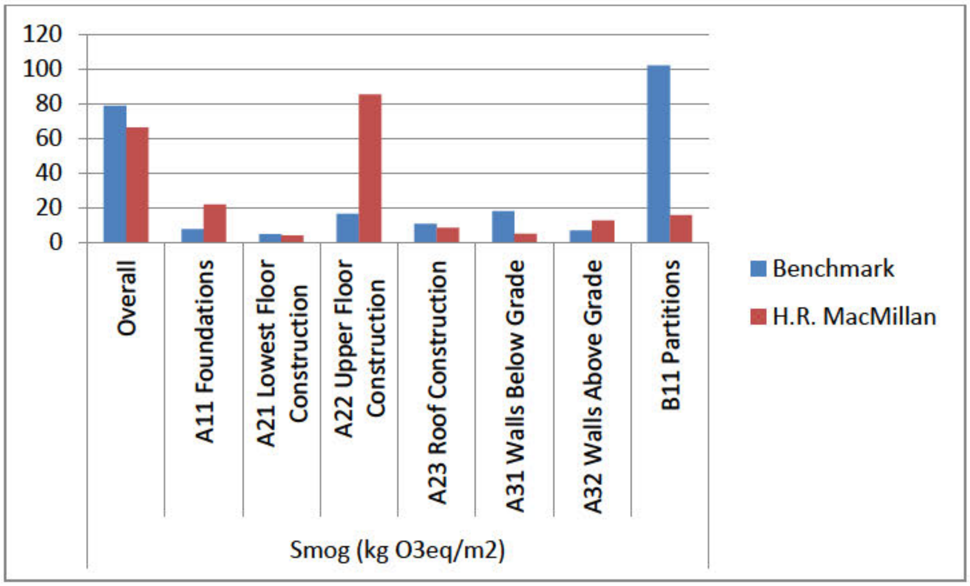

Figure 15 - Smog (kg O3eq/m2) of H.R. MacMillan and Benchmark

Figure 16 below shows a plot of all the different building with their corresponding costs ($) on the y axis and global warming potential (kg CO2eq/m2) on the x axis. The red dot is the plot for the H.R. MacMillan building which lies on the cheaper but higher global warming potential. The best type of building would be the once closest to the 0,0 plot.

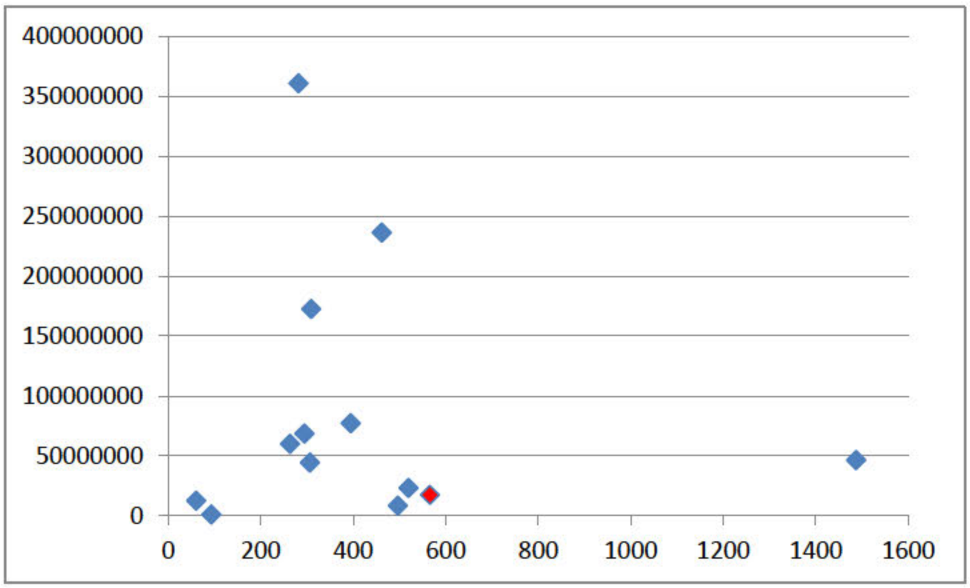

Figure 16 – Total Cost and Global Warming Potential Impacts

Annex B - Recommendations for LCA Use

Using LCA in building design is essential in building sustainable buildings. There are many things that should be taken into consideration when creating a LCA study. In this study only the product and construction stages were addressed, however, the use and end of life stages are very important in an LCA study as well. The Use stage would contribute towards the savings in the impact assessments discussed previously. In the use stage, we can see the savings incurred when building a sustainable building because a sustainable building will undoubtedly cost more and possibly have more impacts in the product and construction stage but might be better in the overall life of a building. The end stage varies greatly in the different regions and their ability to dispose of the waste sustainably.

Another factor that should be considered in an LCA study is the quality of data and benchmarks for buildings and products. Since LCA is a new field, a better database that integrates cost and allows greater variability would need to be developed in order to aid in an LCA study. The availability of data, especially with older buildings is also very important. However, what is more important is the quality of data being presented. A great attention to detail and time is required in design an LCA study as these may affect the results greatly. Since this study will be used in creating a benchmark for other buildings, the data presented must be reliable and very accurate.

Furthermore, prioritizing impact categories and their interpretation is crucial in the use of an LCA study. The impact category that this study focused around was the global warming potential because the students in CIVL 498C determined this to be the most important. However, the other impacts are also very important, and depending on whom the LCA study is intended for, this may change. It should be noted however, that all of the impact categories are closely related and therefore, the effects of one affects the others.

Annex C - Author Reflection

Prior to completing this LCA study, I had very little exposure to LCA. I was introduced to LCA in a 2nd year Materials Engineering course in which we had to look at the cost of different materials in terms of manufacturing and delivery and their corresponding global warming effects. Throughout this course I have learned quite extensively about what goes into an LCA study. From the goal and scope of a LCA study, to modelling a building and even life cycle costing, there were plenty of topics covered in the course. We looked closely at the impact categories and determined which, as students, we believe to be the most crucial and we also learned about CIQS Level 3 categorizing.

I enrolled into CIVL 498C because I was interested in seeing the difference and effects of different building operations and products. The acquisition of data, in order to build a good and reliable database that can be used by students was also interesting, because although the task might be tedious, the importance of it is very great.

	Graduate Attribute			
	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your final project experience.
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A = applied	In order to apply what was learned in the course into the projects, I had to demonstrate my knowledge base, which I acquired throughout the course.
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	I = introduced	There could have been instances in which problem analysis could have been applied in this project, but I ran into very little to no problems due to a very good report that was previously completed.
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and	DA = developed & applied	This was essential in the final project as we were only interpreting the previous student's report. My ability to investigate was developed and applied in this project.

		interpretation of data and synthesis of information in order to reach valid conclusions.		
4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	I = introduced	There could have been instances in which design could have been applied in this project, but I ran into very little to no problems due to a very good report that was previously completed. There were minimal design flaws that were addressed in the reports
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	IDA = introduced, developed & applied	The introduction of Athena Impact Estimator and OnScreen Takeoff expanded my knowledge in different engineering tools that could be used and applied to further LCA studies

6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	N/A = not applicable	Not Applicable
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	DA = developed & applied	This skill was developed and applied in this project in order to properly communicate the complex data acquired in the study.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	ID = introduced & developed	Professionalism was definitely introduced and developed in this project. Although I could have applied it better by handing in the project on time.

9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	IDA = introduced, developed & applied	This course is all about the impact of engineering on society and the environment. This is why LCA was developed and was introduced, developed and applied thoroughly in this project.
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	N/A = not applicable	
11	Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	A = applied	Acquiring the Net Present Value for all the buildings allowed for the application of economics in this project.

12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	A = applied	This project has shown me what I need to learn and improve in order to adapt to the changes that are going on in the world. LCA is a growing field and this project has allowed me to apply this attribute of life-long learning