UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Life Cycle Analysis (LCA) of Doug Mitchell Thunderbird Sports Centre

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This study is part of a larger study – the UBC LCA Project – which is continually developing. As such the findings contained in this report should be considered preliminary as there may have been subsequent refinements since the initial posting of this report.

If further information is required or if you would like to include details from this study in your research please contact rob.sianchuk@gmail.com.

LCA of Doug Mitchell Thunderbird Sports Centre

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1 Abstract

A life cycle assessment of the Doug Mitchell Thunderbird Sports Center (DMTSC) on the University of British Columbia campus was conducted to determine the environmental impacts related to its manufacturing and construction. Eight impact categories were considered including global warming potential, weighted resource use and fossil fuel consumption. This study did not include the impacts associated with operating energy, maintenance or end-of-life. This is one study in a series of studies on three sports facilities, the others being the Richmond Olympic Oval and the old Thunderbird Arena on the same site as the DMTSC.

DMTSC is a sports arena with two skating rinks and up to 7500 seats. A third skating rink remains from the old Thunderbird Arena and is attached to the West side of the building. The DMTSC is currently home to the UBC Thunderbirds Ice Hockey Team and played a large role in the 2010 Winter Olympic Games as a venue for Ice Hockey and Sledge Hockey.

DMTSC is a primarily concrete building. Several of the most common materials include PVC membranes, concrete blocks, foam polyisocyanurate, 30MPa concrete and steel rebar. On-Screen Takeoff Pro was used to quantify all the building materials and the Athena Impact Estimator was used to calculate the associated impacts. Assumptions were required in several stages, and these are documented and accounted for in this report. Over 48 million kg of CO2 equivalent were created in the manufacture and construction of the DMTSC and over 23 million kg of weighted resources.

2 Introduction

The Doug Mitchell Thunderbird Sports Center, located at 6066 Thunderbird Boulevard, University of British Columbia (UBC) Vancouver Campus, is a LEED Silver certified arena facility constructed between 2006 and 2008. The Sports Center is named after Doug Mitchell, a UBC alumnus. The Center was built around an older hockey facility, originally constructed in 1963. In this report, the Center is referred to as the New Thunderbird Arena (NTA), in order to distinguish it from a similar study of the original building.

Architecture services for the construction of NTA were provided by Kasian Architecture and the building construction cost $47.8 million. Currently the building is home to the UBC Thunderbirds Ice Hockey Team and is frequently used for live concerts. NTA played a significant role during the 2010 Winter Olympic and Paralympic Games, serving as a venue for Ice Hockey and Sledge Hockey.

NTA features two ice rinks and seating for up to 7500 people. Additionally, there are areas designated for retail, storage, administration, utilities and other uses. NTA is primarily reinforced concrete construction, with a roof composed of steel.

This report seeks to quantify the environmental impact potential associated with the manufacture and construction of NTA using the Athena Impact Estimator software package and the Tool for the Reduction and Assessment of Chemical and other Impacts (TRACI).

3 Goal and Scope

3.1 Goal

This Life Cycle Assessment (LCA) of the NTA at the University of British Columbia was carried out as an exploratory study to determine the environmental impact of its construction and design. This LCA of the NTA is also part of a series of three reports being carried out simultaneously on respective arenas around Vancouver with the same goal and scope, one being the Richmond Olympic Oval, and the other being the Old Thunderbird Arena. As part of the Old Thunderbird Arena was deconstructed in order to construct NTA, the End-of-Life impacts associated to that building have been added to the construction of this one as part of the earthworks section[1].

The main outcomes of this LCA study are the establishment of materials inventory and environmental impact references for the NTA. Applications of these references may involve the assessment of potential future Olympic or other sports facilities construction projects around the world. This study is also one more added to the list of current LCA projects completed at UBC, bringing the total number of buildings assessed on campus to 37. This information will enable researchers to conduct environmental performance comparisons across the many LCA-studied buildings of UBC over time, comparing different materials, structural styles, building functions, and the impact of construction on student life and the environment. Furthermore, as demonstrated through these potential applications, this NTA LCA can be seen as an essential part of the formation of a powerful tool to help guide and inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future UBC and Olympic 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

[1] The impacts associated with the deconstruction of the Old Thunderbird Arena were calculated in a separate report entitled *Civil 498C Life Cycle Assessment Report: Thunderbird Old Arena.* The authors of that report, Dennis Fan, Hillary Kernahan, Josh Ruddock and Sean Geyer were contacted and agreed to provide the information.

involved in creating policies and frameworks for sustainable development on campus. A second core audience includes VANOC (Vancouver Olympic Committee), the IOC (International Olympic Committee) and any other future Olympic host city. Other potential audiences include developers, architects, engineers and building owners involved in design planning, as well as external organizations such as governments (political, governing sports bodies), private industry and other universities whom may want to learn more or become engaged in performing similar LCA studies within their organizations.

3.2 Scope

The product systems being studied in this LCA are the structure, envelope and construction associated with the NTA on a general square foot and functional area square foot basis. Other functional units include estimating the impact potential per event attendance for hockey games, concerts and graduation ceremonies. Also, impact potential will be estimated on an athletic use basis, on the assumption that both rinks in the new facility are being used by two full hockey teams of 20 players each. 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 NTA, as well as associated transportation effects throughout. As mentioned, the deconstruction of the Old Thunderbird Arena is also included in earthworks prior to construction.

3.3 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.

This study first examines the initial stage of a materials quantity takeoff. This process involves performing a variety of measurements of the building's structure and envelope. These include linear, area and count conditions as called by OnScreen.

OnScreen TakeOff version 3.7.0.12 is used, which is a software tool designed to perform material takeoffs with increased accuracy and speed. Using imported digital blueprints, the program simplifies the calculation and measurement of the takeoff process, while reducing associated error. The measurements generated are formatted into the inputs required for the IE building LCA software to complete the takeoff process.

Using the formatted takeoff data, version 4.1.13 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 NTA in the Vancouver region as an athletic building type. The IE software is designed to aid the building community in making more environmentally conscious material and design decisions. The tool achieves this by applying a set of algorithms to the inputted takeoff data from OnScreen 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, 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 of the NTA. As this study is a cradle-to-gate assessment, the expected service life of the NTA 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 measurements 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). In order to generate a complete environmental impact profile for the NTA, 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 measurement results, a sensitivity analysis is then conducted in order to reveal the effect of material changes on the impact profile of the NTA.

The primary sources of data for this LCA are the original architectural and structural drawings for NTA. The NTA was initially constructed in 2008-2010. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as the associated envelope and openings (i.e. doors and windows) within each of these assemblies. As well, this includes the seats for the arena as they are fixed into place and not a furnished add-on. The decision to omit other building components, such as electrical aspects, HVAC system, finishing and detailing, etc., are associated with the limitations of available data and the IE software, to minimize the uncertainty of the model as well as not taking operational and energy usage into account. In the analysis of these assemblies, certain undetermined assumptions may be required if detailed data cannot be determined from the NTA building drawings in order to complete the study in IE. Furthermore, there are inherent assumptions made by the IE software in order to generate the bill of materials and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitations will be discussed further as the energy in the Building Model section.

As this is for a university course, a critical review of the LCA study is not required at this time. Also, a comparative assessment of the NTA, Richmond Oval and Old Thunderbird Arena was not considered feasible due to time and resource constraints on this project.

4 Building Model

4.1 Takeoffs

Performing an accurate life cycle assessment requires an accurate quantity takeoff of all involved building materials. For the LCA of the NTA, quantity takeoffs were performed with the On-Screen Takeoff Pro (OST) software package, version 3.8.1.36.

Initially, all provided drawings were loaded into the OST. OST provides a tool to calculate the scale for the drawings such that it is saved by the software and the user is not required to use the scale in further calculations.

The OST software offers three options or conditions for performing quantity takeoffs; linear, area and count. Linear conditions allowed the user to numerically input the width and height and graphically trace the length on the construction drawings. Linear conditions were used for measuring items such as strip footings and walls of uniform height. Area conditions allowed for numerical input of thickness and graphical input of height and width. Typically, area conditions were used for floors, roofs, and walls which varied in height. Finally, the count condition required numerical input of all three dimensions. Count conditions were used for columns, beams, and pad footings. In some cases, multiple conditions were combined to model an assembly. For example, while area conditions were used to model walls, the spaces missing from the walls (doors and windows) were counted and automatically subtracted from the area by OST. Some interaction between these takeoffs has been programmed into OST, but as different assemblies were modeled on different copies of the blueprints, this was not taken advantage of.

There were some challenges that needed to be overcome in the completion of the takeoffs in this LCA. First of all, large areas of the building are visible in more than one of the provided drawings. This makes it possible to double-count the quantities of a given area. To avoid this, the various assemblies were divided among team members and careful communication was relied upon in cases where an assembly was not clearly defined, such as a sloped surface that served as a wall and a floor. Additionally, the bulk of the take-offs were performed on the structural drawings, reserving the architectural drawings for reference. This eliminated many of the instances of assemblies being visible on more than one drawing. A second potential problem was caused by discrepancies between assembly schedules and their representations on the drawings. This was not a frequent occurrence, and where it arose, the assembly schedule was taken to be correct. Similarly, in some cases, the structural drawings provided information or dimensions which conflicted with the architectural drawings. Where this happened, the structural drawings were taken to be correct.

A final challenge arose when data was missing as some assemblies were unlabeled. The dimensions for these assemblies were assumed based on the dimensions of similar assemblies. Due to the limited timeframe, all four team members conducted takeoff measurements on separate assemblies and the data was combined afterwards.

4.2 Modeling Assumptions

Several assumptions and simplifications were applied to all assemblies. First of all, information regarding the fly-ash content of the concrete was not available. A discussion with the architect of the building revealed that UBC typically has high standards for concrete quality. As a result, concrete in the NTA has been assumed to contain an above-average quantity of fly-ash; 35%. Additionally, the standardizations applied to the beam and column assemblies were applied, to a lesser degree, to the other assemblies. This study focused on the structural components of the structural components of the building, and, as such, many of the architectural features were outside the scope of this work.

Appendix B contains the IE Input Assumptions Document, a description of the required assumptions for each assembly. Where possible, reasoning behind these assumptions is also provided. The companion document to the Input Assumptions, the IE Input Document can be found in Appendix A. This document provides the details on each assembly as they exist in the building in conjunction with the assembly details as they were modeled in the IE.

4.2.1 Footings

As mentioned earlier, footing assemblies were modeled using linear conditions for strip footings and count conditions for pad footings. The rebar details were not included for some of the footings, and were estimated based on rebar sizes present in footings of similar size. Additionally, some footings contained more than one size of rebar. Unfortunately, the IE only accepts one rebar size per assembly and, as a result, a representative rebar size was chosen. The actual depth of a footing depends on the elevation of the soil beneath the footing. As this value was not recorded during construction, the footings were assumed to be as deep as the design suggested.

4.2.2 Walls

Walls were modeled using both area conditions and linear conditions, as required. For main walls, the thickness and height were numerically inputted and a linear condition was used. Window area in the walls was modeled with area conditions. Doors and other openings associated with the walls during the linear and area condition modeling, in order to aggregate them into a single input for the IE, and then removed later using a count condition.

4.2.3 Columns and beams

Columns and beams were modeled using count conditions. The strict metrics of the IE meant that not all beams could be inputted in their original dimensions. Instead, the dimensions were modified to preserve their volume, while meeting the input requirements of the IE. This standardization also decreased the level of difficulty of inputting members into the IE as it increased the number of members with the same dimensions.

4.2.4 Floors

Floors were modeled using area conditions. Where floors assemblies were the same on either side of a wall, the floor was assumed to be continuous underneath the wall. Loading conditions on the floors and roofs was not always known, though those that are known are designed for 4.8 kPa, so any floors missing this data were assumed to have the same design live load. Where these floor takeoffs contacted each other next to or underneath walls varies from takeoff to takeoff and is the main source of uncertainty.

Due to the irregular shape of many of the floors, dimensions were modified as they were input into the IE so that the total volume was preserved while preventing the span from exceeding the maximum allowable in IE for one assembly. This maximum span is 21.2m for open web steel joist floors and 9.75m for concrete suspended slabs.

Due to the limitations on thickness sizes for slabs-on-grade in the IE, the total volume for each slab-on-grade was calculated, and then a new square area chosen based on thicknesses available in the IE so as to preserve the total volume of concrete being measured. The polyethylene vapour barrier used in the slabs-on-grade is a common choice and available in the IE. Due to the options available in the IE, concrete strength has been rounded up from 25 to 30 MPa for some cases; many of the concrete floors were already designed to be 30 MPa.

All steel deck floors in NTA are assumed to be open web steel joist floors with concrete topping. However, the IE assumes all such floors have 89mm of topping, and descriptions in the structural drawings indicate that the concrete topping in some floors exceeds 200mm. Because of this difference, the extra topping beyond the default for open web steel joist floors has been calculated for volume and added as an extra basic material of 30 MPa, 35% fly ash concrete, totaling 205 m^3.

In the structural drawings, the fireproofing used on the underside of the steel decks is only described as “spray fiber” with thickness determined by fire resistance rating. As no precise thickness associated with this combination of fireproofing and rating could be found, it was assumed as blown/sprayed cellulose. Based on the appearance of these decks, it is also assumed that the thickness of the insulation was a minimum of approximately 1 inch.

There is an AV room on the fourth floor of the main arena, accessible by the catwalks suspended from the ceiling. Live load details for the floor in this room were not found, but it is assumed that it is the same as the rest of the floors and roofs, which is 4.8 kPa. Also on the fourth floor, the announcer’s box is on a concrete walkway of indeterminate thickness. Though evidently thicker in the section drawings, this area is assumed to be a suspended slab of default thickness in the IE.

Similar to the steel deck floors, the IE imposes a maximum span length for suspended slab floors, so the dimensions are adjusted to maintain the same total floor area. Fly ash data was not found for these floors as well, so it is assumed that the fly ash amount is the same as the slabs-on-grade.

4.2.5 Roofs

It is assumed that all steel deck roofs belong to the open web steel joist category. In the structural drawings, the live load on the roofs is stated as 1.8 kPa plus snow loads for the flat roofs, and 2.0 kPa plus snow loads for the sloped main arena roof. In structural sheet S0, it is stated that the snow load Ss is 1.9 kPa. The total live load is therefore rounded up to 4.8 kPa for the IE.

Most of the roof makes use of a TPO (Thermoplastic PolyOlefin) roofing system, which is not an available selection in the IE. It was determined that a PVC membrane roofing system would be the closest option, with foam polyisocyanurate insulation. This assumption leaves out the gypsum board that is used in the roof, so it is added in the IE separately.

The roof through the center of the building, along the main south rink concourse, uses an SBS roofing system which corresponds to a modified bitumen membrane roofing system, so it has been assumed that this is the roofing system used above the concourse. After a check on the materials used per thickness of the roofing system, it is assumed that the thickness as set in the IE corresponds to the thickness of the polyisocyanurate layer. The eaves around the south rink use a roofing system with no apparent vapour barrier or insulation, so it is assumed that it only contains gypsum board, the steel and a PVC membrane.

4.2.6 Stairs

All stairs are assumed to have a rise-to-run of 1:1.5, based on inspection of the section drawings and on-site. Therefore, the surface area of materials that cover both the rise and run of the stairs would be approximately 1.67 times greater than the vertical projection obtained from OnScreen.

Details in the structural drawings regarding stairs are less specific than the rest of the flooring. For the concrete stairs, a thickness of 200mm is mentioned in the structural drawings and the fly ash and strength of the concrete is assumed to be the same as the slabs. The volume was then calculated and added as extra basic materials.

The steel staircases make use of steel stringers on either side of the stairs and steel tread pans filled with concrete. The concrete is assumed to be 1 inch deep in each pan. The steel volume and weight per metre run of staircase was estimated for the stringers based on dimensions supplied in the structural drawings. The steel weights and concrete volume were then added as extra basic materials assuming a density of steel equal to 8 tonnes per cubic metre. The tread pans are assumed to be made from galvanized decking. No handrail or support post details were found in the sheets available so they were not modeled with takeoffs.

4.2.7 Earthworks

Earthwork quantities were modeled using area conditions. Using section cuts, excavation depths were estimated for various regions of the building, which, when multiplied by the area, yielded the volume of displaced earth. Major assumptions were unavoidable in determining this volume as it was impossible to know with certainty the in-situ soil conditions. It was assumed that before construction the soil elevation was similar to the ground level around the perimeter of the building after construction. Once the volume was calculated, the associated impacts were determined using an LCI developed in a Swedish study by the IVL Swedish Environmental Research Institute. Using the 1998 Geomap Vancouver prepared by Geological Survey of Canada, the soil conditions were taken to be till, and sand mixed with gravel. This yielded an excavation class of 2, or medium workability and a swelling factor of 1.17. The distance traveled to dispose of excavated soil by the dumper is unknown and, as a result, the impacts associated with this transport and disposal have been left outside the scope of this study.

In addition to the impacts associated with the earthworks of NTA, the impacts associated with the deconstruction of the Old Thunderbird Arena and excavation have been included under the earthworks section. This is to take into account that the construction of NTA *required* the deconstruction of the old building, even though it might have had a useful lifetime still ahead of it.

Table 1 summarizes the results of the earthworks-related impacts.

Earthworks Process	Substance	Inventory Analysis		Impact Assessment					
		Emission Type	Total Amount Emitted (kg)	Global Warming (kg CO2 eq)	Ozone Depletion (kg CFC-11 eq)	Smog (kg NOx eq)	Acidification (H+ moles eq)	Respitatory Effects (kg PM2.5 eq)	Eutrophication (kg N eq)
Excavator									
	Carbon dioxide	Air	1.18E+02	1.18E+02					
	Sulfur dioxide	Air	8.50E+03				4.31E+05	2.05E+03	
	Nitrogen oxides	Air	4.07E+00			4.07E+00	1.63E+02	1.69E-01	1.80E-01
	Particulates, > 10 um	Air	7.68E+01					4.61E+01	
	Carbon monoxide	Air	3.06E+00	4.81E+00		4.10E-02			
	Hydrogen chloride	Air	1.72E-01				7.70E+00		
	Methane	Air	5.55E+00	1.28E+02		1.64E-02			
	Phenol	Water	4.31E-02						
	COD, Chemical Oxygen Demand	Water	6.13E-02						3.06E-03
	Nitrogen	Water	1.29E-01						1.27E-01
Dumper									
	Carbon dioxide	Air	1.76E+04	1.76E+04					
	Sulfur dioxide	Air	8.49E+00				4.31E+02	2.04E+00	
	Nitrogen oxides	Air	1.59E+02			1.59E+02	6.38E+03	6.61E+00	7.06E+00
	Particulates, > 10 um	Air	6.35E+00					3.81E+00	
	Carbon monoxide	Air	1.90E+01	2.98E+01		2.54E-01			
	Hydrogen chloride	Air	1.15E+01				5.13E+02		
	Methane	Air	1.12E-02	2.57E-01		3.31E-05			
	Phenol	Water	1.27E-01						
	COD, Chemical Oxygen Demand	Water	2.68E-01						1.34E-02
	Nitrogen	Water	4.24E-02						4.18E-02
Totals				1.79E+04	0.00E+00	1.64E+02	4.39E+05	2.10E+03	7.42E+00

Table 1 – 4.2.7 Earthworks Impacts

5 Results and Discussion

5.1 Bill of Materials

Table 10 - A.1 represents a bill of the construction materials that make up the NTA. The total quantity of each material is shown for each assembly, as well as for the building as a whole. Five of the materials present in the largest quantity include PVC membrane, concrete blocks, foam polyisocyanurate, 30MPa concrete and steel rebar.

PVC membrane was substituted for TPO as TPO was not a material option in IE, and after some research it was decided that PVC was the closest option available in IE. It covered two of the main roof spaces on the NTA, and there was approximately 56,000 square meters used.

Concrete blocks in the NTA were used in many of the interior wall assemblies and numbered 81450 in total.

Rebar, Rods and Light sections saw use throughout the entire building. Close to 250 tonnes of rebar were used, with approximately 75% of that in the walls. In some cases, IE metrics wouldn't allow for the correct input dimensions of the rebar, and, as a result, this number is probably an overestimate. Additionally, some footings had more than one size of rebar present while the IE only allows for one rebar size per footing. In these cases, the larger size was chosen, adding further to the overestimate. Fortunately, these over-counts were only necessary on some of the footings and a small portion of the walls, maintaining the validity of this result.

Concrete was used in the foundations, walls, floors, and the columns in Rink A that are supporting the risers. Just over to 5500 m^3 of 30MPa concrete was used, about half of which was in the floors. Other densities of concrete were used in a few places, but the total volume of all these other instances was less then 10% (or 550 m^3) of the 30MPa use. Adjustments to ensure constant volume between modeling and IE input mean that this quantity is probably relatively accurate. Fly-ash content was not known for this concrete and was assumed to be 35%. If, in fact, the actual fly-ash content was lower than this, it would not have an effect on the concrete volume, but it would decrease the impacts associated with the concrete. Additionally, if the actual rebar volume was lower than predicted, the concrete volume would increase marginally.

Foam polyisocyanurate was used in the floors and the walls of the NTA and totaled in excess of 22 000 m^2 at a thickness of 25mm. In the roofing system, it is mentioned in the architectural notes that the polyisocyanurate layer of insulation was applied in 2 layers with staggered joints. In this case and after examining the roof schedule in the architectural notes, it was assumed that one layer was applied evenly across the entire surface.

5.2 Impact Assessment and Sensitivity Analysis

The following subsections present the total environmental impacts of NTA in each of the eight categories introduced in the Goal and Scope, Section 2.3, namely

- Global warming potential,
- Acidification potential,
- Eutrophication potential,
- Ozone depletion potential,
- Photochemical smog potential,
- Human health respiratory effects potential,
- Weighted raw resource use, and
- Fossil Fuel Consumption

Each subsection further breaks down the result such that it is possible to determine which assembly group most contributes to each impact category. Within each assembly group, the impacts are divided between Manufacturing and Construction impacts. Impacts associated with the Earthworks are not affiliated with any other assembly group and are simply added to the building total for each impact category.

This study deviates from ISO 21931-1 in that Raw Material Supply and Manufacturing impacts are reported under the Manufacturing heading and Earthworks impacts are kept separate from Construction impacts.

The following is a description of each impact category and the NTA results.

5.2.1 Global Warming Potential

Global Warming Potential is an impact categorized by the Intergovernmental Panel on Climate Change (IPSS) that uses a category indicator of kilograms of Carbon Dioxide equivalent. This category seeks to estimate the extent to which the construction of this building will contribute to increases in the earth's temperature based on the potential of the emissions released to absorb infrared radiation and heat the atmosphere. Characterization factors for Global Warming Potential were developed by the Intergovernmental Panel on Climate Change (IPCC).

Table 1 lists the global warming potential for each assembly group and life cycle stage. In total, the manufacturing and construction of NTA created the equivalent of 4.9 million kilograms of Carbon Dioxide. Approximately 70% of this impact was caused by the floor, roof and wall assemblies. This is likely due to a high volume of concrete in these assemblies. During concrete manufacturing, a large amount of Carbon Dioxide is released. Over 78% of the global warming potential is generated in the manufacturing materials stage of the life cycle. Again, this is likely due to the large amount concrete manufacturing required.

Life Cycle Stage	Process	Assembly Group						
		Floors	Roof	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	1083776.1	884984.4	1216327.5	295206.2	182858.1	79225.5	3742377.8
	Transport	33154.6	15977.8	28367.0	11541.7	4603.7	2881.9	96526.7
	Total	**1116930.8**	**900962.1**	**1244694.5**	**306747.9**	**187461.8**	**82107.4**	**3838904.5**
Construction	Earthworks							806339.7
	Material	46297.7	4194.9	26446.9	4551.0	72.0	0.0	81562.5
	Transport	46482.8	40867.9	43139.8	15983.7	4551.9	4007.1	155033.2
	Total	**92780.5**	**45062.8**	**69586.7**	**20534.6**	**4623.9**	**4007.1**	**1042935.4**
Total		1209711.3	946025.0	1314281.2	327282.6	192085.7	86114.5	**4881839.9**

Table 2 - 5.2.1 Global Warming Potential

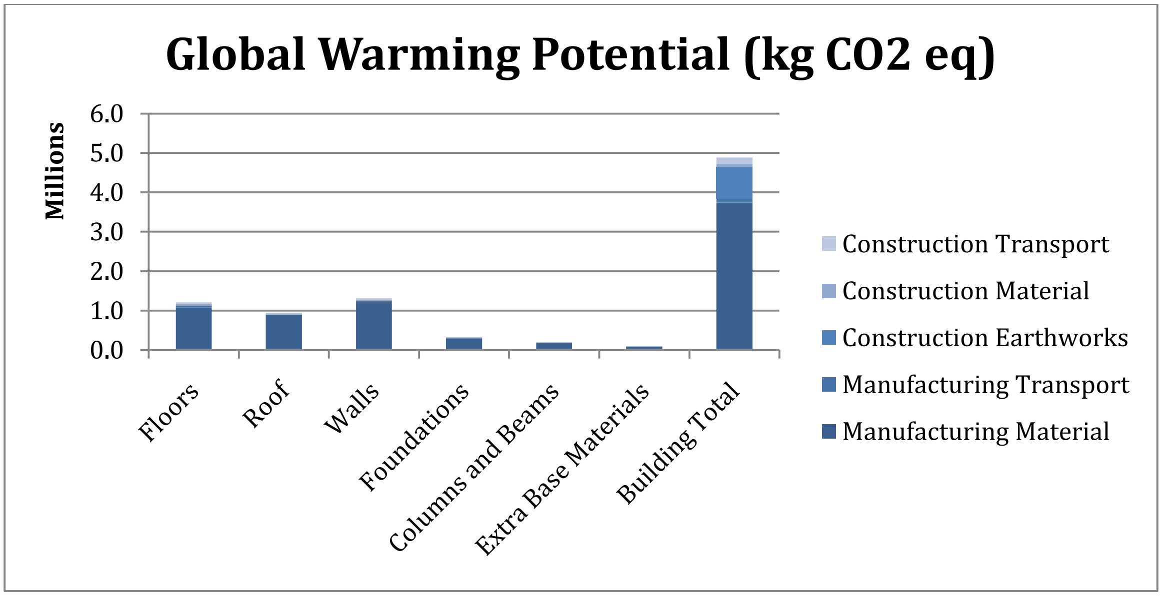

Figure 1 - 5.2.1 Global Warming Potential

As we can see from the sensitivity analysis below, our assumptions about the majority of global warming potential arising from concrete manufacturing seem to be confirmed, with a 10% increase in 30MPa concrete resulting in a 3.22% increase in global warming potential, as compared to the other four materials generating less than a 0.5% increase.

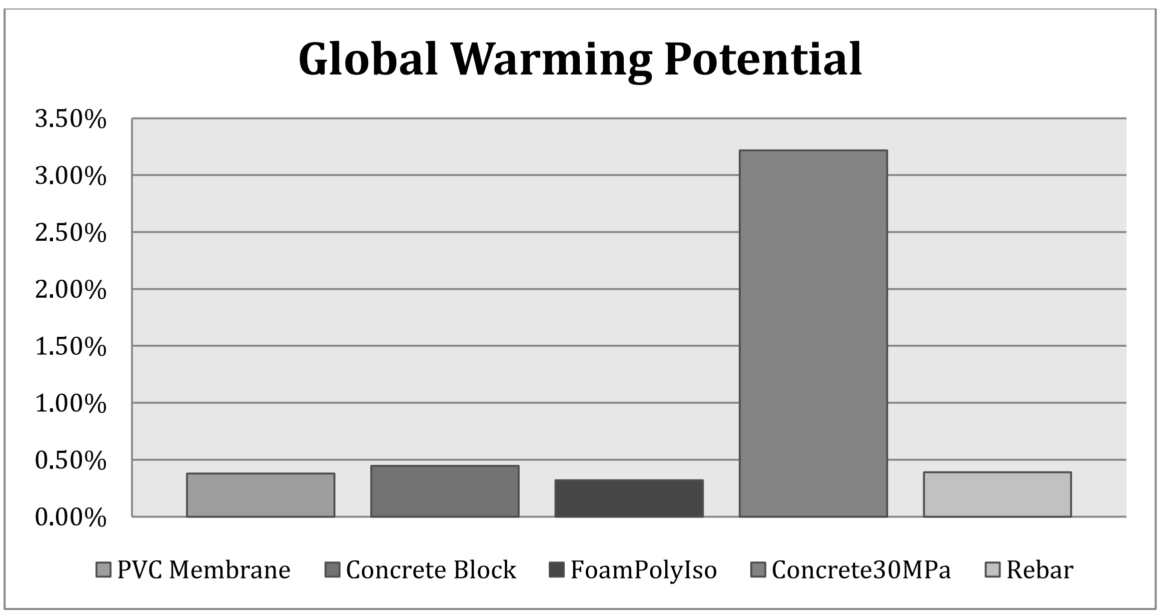

Figure 2 - 5.2.1 Global Warming Potential Sensitivity Analysis

5.2.2 Acidification Potential

Acidification potential is an impact category that equates air emissions in equivalent moles of Hydrogen ions. Hydrogen ions that reach the environment cause an increase in the pH of soils and water bodies and can cause acid rain, decreased forest and plant health and a hostile habitat for many animals. How much impact a given amount of Hydrogen Ions has on the environment depends largely on the location where precipitates are deposited, as some systems will have a better buffering capacity. That is to say that some systems are more capable than others at absorbing an amount of acid without it having a large effect on their pH.

In total, the construction of NTA contributed about 2.3 million moles of hydrogen ion equivalents to the environment. The floors, walls, roof and earthworks are all a large part in this with each producing approximately 500 000 moles. Greater than 70% of the moles of hydrogen ion eq were as a result of material manufacturing.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roof	Walls	Foundations	Columns and Beams	Extra Materials	Building Total
Manufacturing	Material	409751.2	389932.9	569458.1	118006.7	78443.6	31185.5	1596778.0
	Transport	16131.2	6493.6	12191.7	5943.2	1683.7	1483.4	43926.9
	Total	**425882.5**	**396426.5**	**581649.8**	**123950.0**	**80127.4**	**32668.9**	**1640704.9**
Construction	Earthworks							540136.0
	Material	22049.8	3210.0	13338.5	2450.9	39.5	0.0	41088.7
	Transport	15544.9	14738.1	14368.4	5041.2	3349.2	1353.3	54395.0
	Total	**37594.7**	**17948.1**	**27706.9**	**7492.1**	**3388.7**	**1353.3**	**635619.7**
Total		463477.1	414374.5	609356.7	131442.1	83516.1	34022.2	**2276324.7**

Table 3 - 5.2.2 Acidification Potential

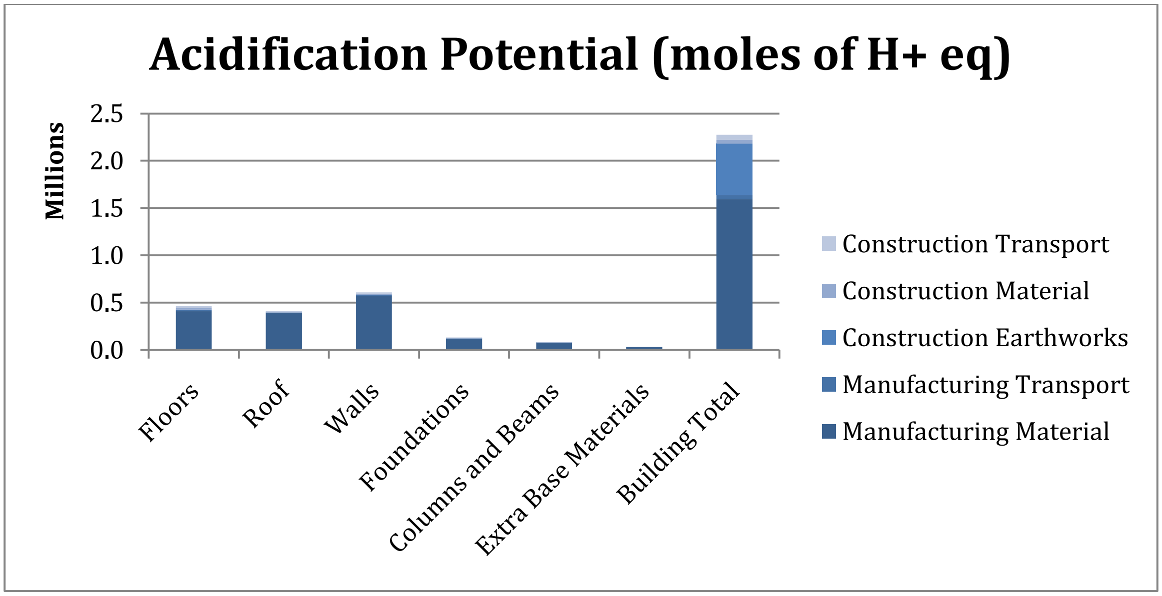

Figure 3 - 5.2.2 Acidification Potential

We start to see more variety in the acidification potential sensitivity analysis. While concrete still dominates the category, with a 3.8% increase occurring, adding 10% PVC to our overall model contributes a 1% increase and concrete block contributes a 0.6% increase. The larger impacts from PVC are most likely attributable to the hydrogen chloride which is released when PVC is heated[2] and has a characterization factor of 44.70 H+ equivalent under TRACI.

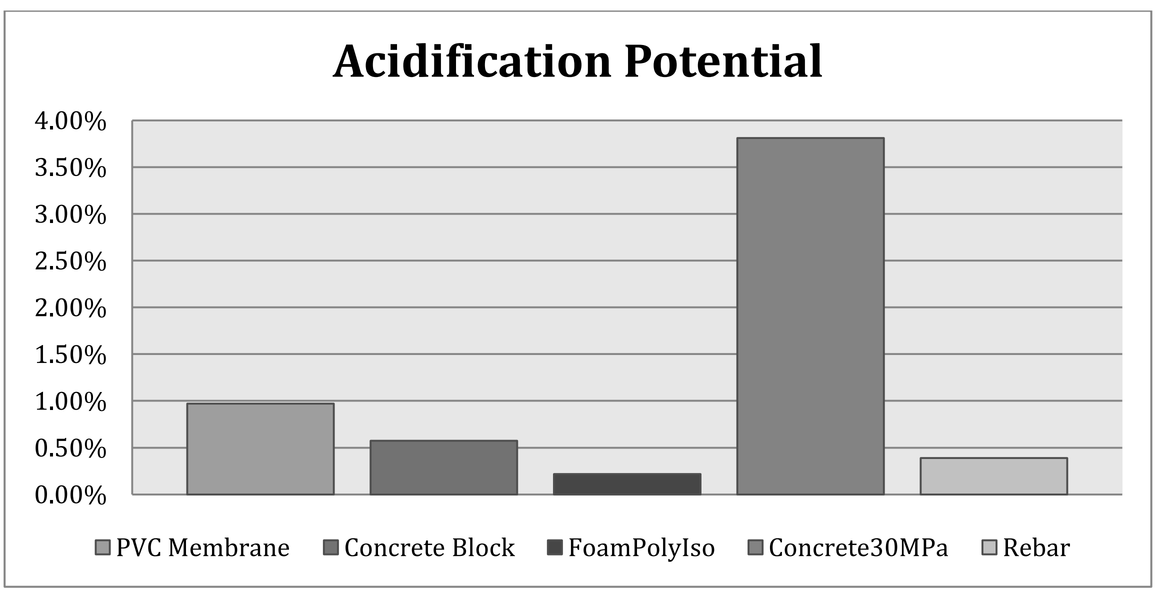

Figure 4 - 5.2.2 Acidification Potential Sensitivity Analysis

[2] http://www.phelios.com/sd/archives/may05.html

5.2.3 Eutrophication Potential

Eutrophication refers to the influence on algae growth in nutrient deficient surface waters and equates water emissions using a category indicator of kilograms of Nitrogen equivalent. Impact estimates of Eutrophication Potential take into account the probability that these chemicals will reach an aquatic environment. Excessive algae growth can lead to an oxygen shortage, the release of toxic leads and, as a result, the death of fish and toxicity to humans.

The construction and manufacturing of NTA released the equivalent of 2500 kilograms of Nitrogen eq into the environment. Approximately 35% of this impact was developed by the wall systems, and slightly less in the roof and floors. Earthworks did not play a large role in the creation of Nitrogen equivalents. For their quantity in the building, columns and beams contributed a significant portion of the eutrophication potential at 244 kilograms N eq or about 10%. This is likely to the high volume of steel used in these assemblies.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roofs	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	518.2	648.5	808.7	81.8	239.3	22.1	2318.7
	Transport	17.1	6.8	12.9	6.3	1.8	1.6	46.4
	Total	**535.3**	**655.4**	**821.6**	**88.1**	**241.1**	**23.7**	**2365.1**
Construction	Earthworks							94.8
	Material	21.9	3.2	13.4	1.5	0.0	0.0	40.0
	Transport	16.2	15.4	14.9	5.2	3.6	1.4	56.7
	Total	**38.1**	**18.6**	**28.3**	**6.7**	**3.6**	**1.4**	**191.6**
Total		573.4	674.0	849.9	94.8	244.7	25.1	**2556.7**

Table 4 - 5.2.3 Eutrophication Potential

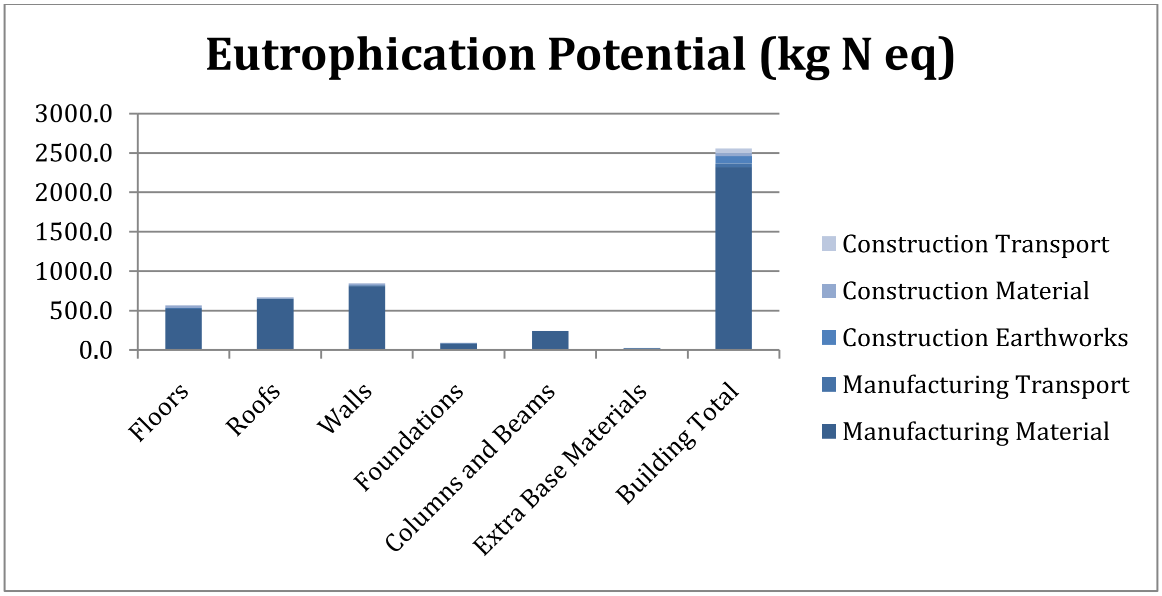

Figure 5 - 5.2.3 Eutrophication Potential

As stated above, steel has a large impact on eutrophication potential, and thus we see this category being equally sensitive to concrete and steel, both with just over a 2% increase. This was the least impacted category by concrete, including concrete block.

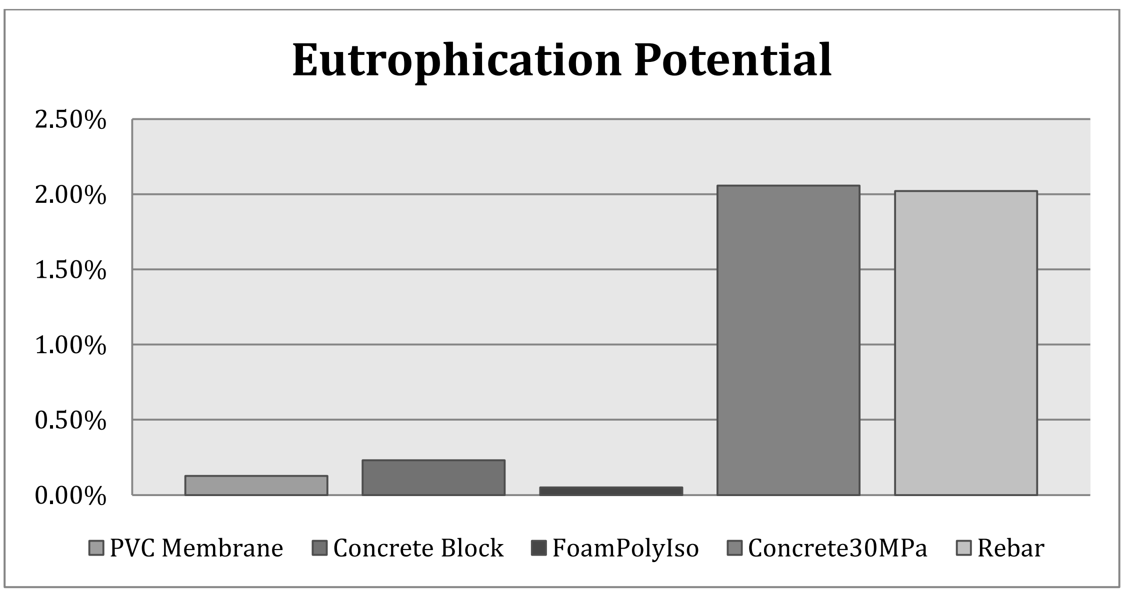

Figure 6 - 5.2.3 Eutrophication Potential Sensitivity Analysis

5.2.4 Ozone Depletion Potential

The Ozone Depletion potential impact category equates air emissions by their potential to change the stratospheric Ozone column causing UVB rays to enter the earth's atmosphere. UVB rays are potentially harmful to humans, animals and crops. Ozone depletion potential uses kilograms of chlorofluorocarbons (CFC-11) equivalents as its category indicator. The ozone layer is located between 40 and 50 kilometers above the earth's surface.

In the manufacture and construction of NTA, 0.0041 kilograms of CFC-11 eq were released into the atmosphere. It is worth noting that 99.7% of this total was attributed to the manufacture of materials. Again the walls and floors were responsible for the majority of this impact, combining to produce greater than 80% of the CFC-11 eq.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roof	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	1.46E-03	2.39E-05	1.85E-03	5.86E-04	6.99E-05	1.43E-04	4.13E-03
	Transport	1.41E-06	6.70E-07	1.19E-06	4.92E-07	1.91E-07	1.23E-07	4.07E-06
	Total	**1.46E-03**	**2.46E-05**	**1.85E-03**	**5.87E-04**	**7.01E-05**	**1.43E-04**	**4.13E-03**
Construction	Earthworks							3.46E-05
	Material	0.00E+00	0.00E+00	4.05E-11	0.00E+00	2.94E-11	0.00E+00	6.99E-11
	Transport	1.91E-06	1.68E-06	1.77E-06	6.55E-07	1.93E-07	1.64E-07	6.37E-06
	Total	**1.91E-06**	**1.68E-06**	**1.77E-06**	**6.55E-07**	**1.93E-07**	**1.64E-07**	**6.37E-06**
Total		1.46E-03	2.63E-05	1.85E-03	5.87E-04	7.03E-05	1.43E-04	**4.14E-03**

Table 5 - 5.2.4 Ozone Depletion Potential

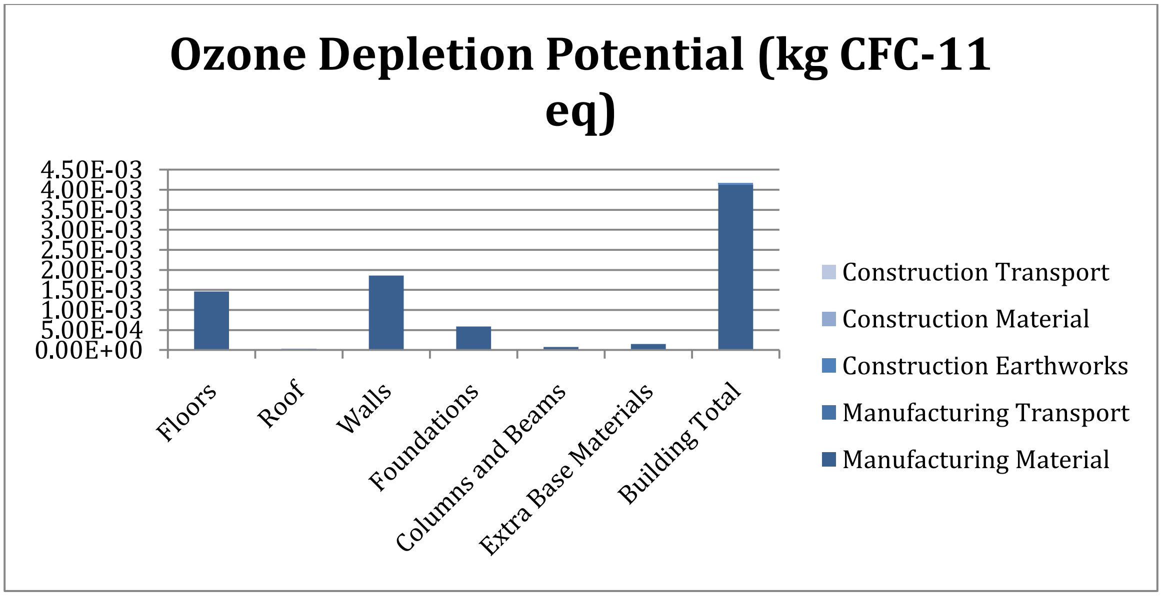

Figure 7 - 5.2.4 Ozone Depletion Potential

We can see that 10% additional concrete, results in nearly a 6% jump in Ozone Depletion Potential. The only other material that registers an impact in this category is the other cementitious material being analyzed, concrete block, with a 0.62% increase.

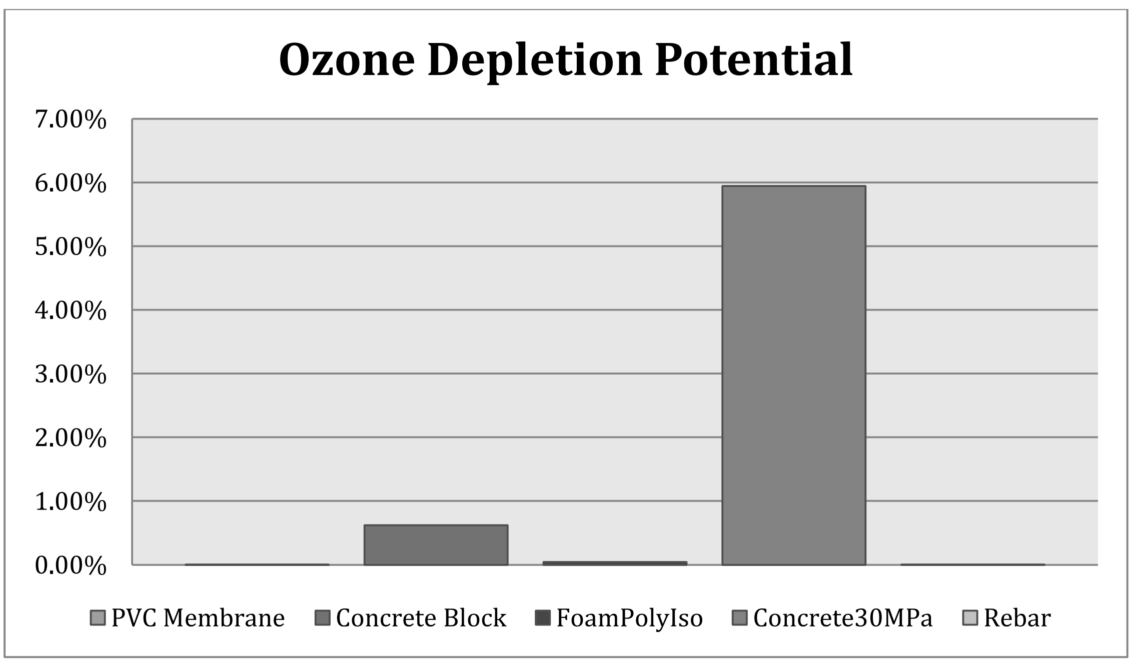

Figure 8 - 5.2.4 Ozone Depletion Sensitivity Analysis

5.2.5 Photochemical Smog Potential

Smog potential categorizes a given emission's influence on the formation of ozone in the troposphere, the layer of the atmosphere closest to earth. Ozone in the troposphere leads to the creation of smog which in turn leads to emphysema, bronchitis and asthma if inhale by humans. It can also cause plant mortality. Smog is a local effect.

In total, the cradle to gate LCA results for the NTA indicates a contribution of 19000 kilograms of $N0_x$ eq to the environment. Over 6000 kilograms $N0_x$ eq of this was as a result of the manufacture and construction of the wall assemblies. 1% of the 19000 kilograms of $N0_x$ equivalence were a result of transportation during the manufacturing and construction stages.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roof	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	4352.5	1590.0	5520.2	1561.8	431.8	385.9	13842.3
	Transport	376.4	149.5	281.7	139.2	38.3	34.8	1019.8
	Total	**4728.8**	**1739.5**	**5801.9**	**1701.1**	**470.1**	**420.7**	**14862.1**
Construction	Earthworks							2123.3
	Material	540.9	80.0	346.4	49.5	0.4	0.0	1017.3
	Transport	349.0	333.3	322.5	112.5	79.2	30.4	1226.9
	Total	**890.0**	**413.3**	**668.8**	**162.0**	**79.7**	**30.4**	**4367.6**
Total		5618.8	2152.8	6470.8	1863.1	549.7	451.1	**19229.6**

Table 6 - 5.2.5 Photochemical Smog Potential

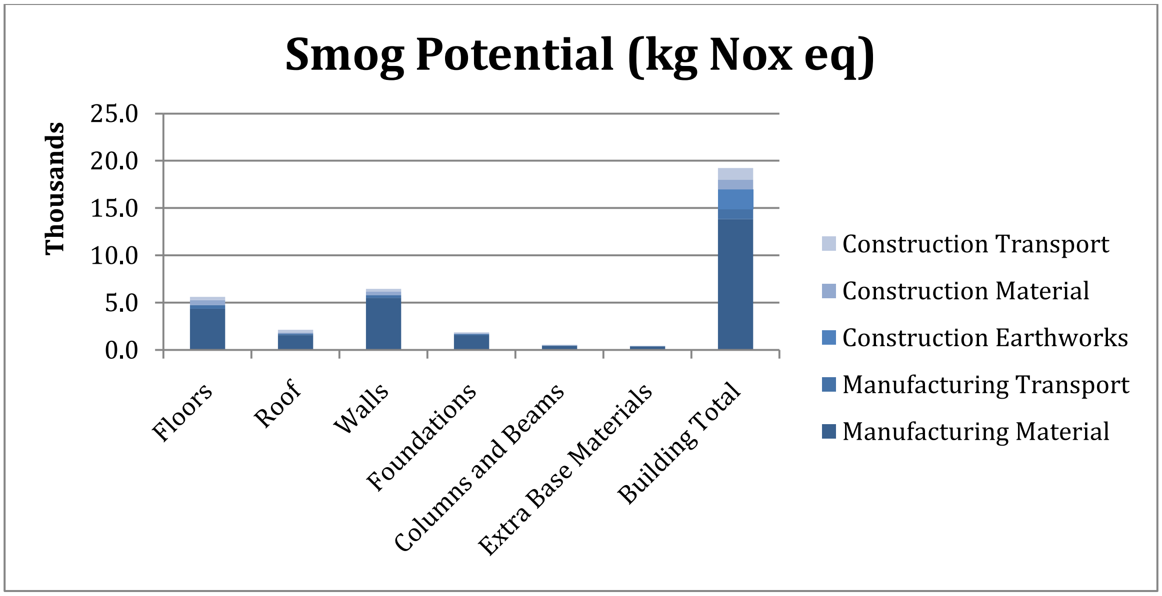

Figure 9 - 5.2.5 Photochemical Smog Potential

Once again concrete is the most impactful material in this category. Nitrous Oxide is an inherent part of the concrete manufacturing process[3] and it should therefore come as no surprise that a 10% increase in concrete resulted in more than a 5% increase in smog potential.

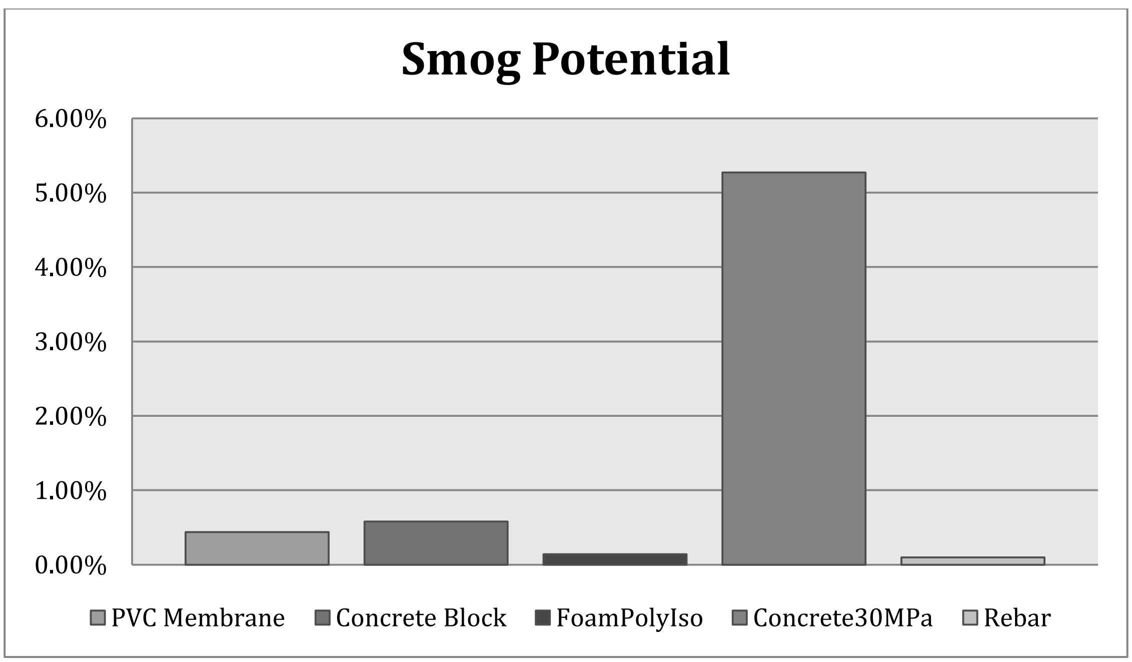

Figure 10 - 5.2.5 Photochemical Smog Potential Sensitivity Analysis

[3] http://www.ec.gc.ca/air/default.asp?lang=En&n=B02E25FD-1

5.2.6 Human Health Respiratory Effects Potential

HH respiratory effects potential are measured in equivalent kilograms of PM2.5. PM2.5 refers to particulate matter which is smaller than 2.5 micrometers in diameter. Particles larger than this are caught in the throat and coughed or sneezed out of the body before they reach the lungs, but this size and smaller are able to penetrate deep into the lungs. If enough PM2.5 reaches the lungs, a deposit can build up inside of the alveoli, causing a reaction and ultimately heath issues or even death. Coughing, asthma, heart disease, bronchitis, emphysema, pneumonia and birth problems have been linked to PM2.5.

The manufacture and construction of NTA created the equivalent of over 13000 kg of PM2.5. 17% of this total was due to the earthworks portion of the construction. Wall assemblies contributed close to 4000 kg of PM2.5 eq, while floors and roof were both near 2700 kg.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roofs	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	2644.9	2817.2	3941.3	840.6	419.7	217.4	10881.0
	Transport	19.7	7.9	14.8	7.3	2.0	1.8	53.5
	Total	**2664.6**	**2825.1**	**3956.1**	**847.9**	**421.7**	**219.2**	**10934.5**
Construction	Earthworks							2213.7
	Material	24.8	3.7	15.2	1.7	0.0	0.0	45.4
	Transport	18.7	17.8	17.3	6.1	4.1	1.6	65.7
	Total	**43.5**	**21.5**	**32.5**	**7.8**	**4.2**	**1.6**	**2324.7**
Total		2708.1	2846.6	3988.6	855.6	425.9	220.8	**13259.2**

Table 7 - 5.2.6 Human Health Respiratory Effects Potential

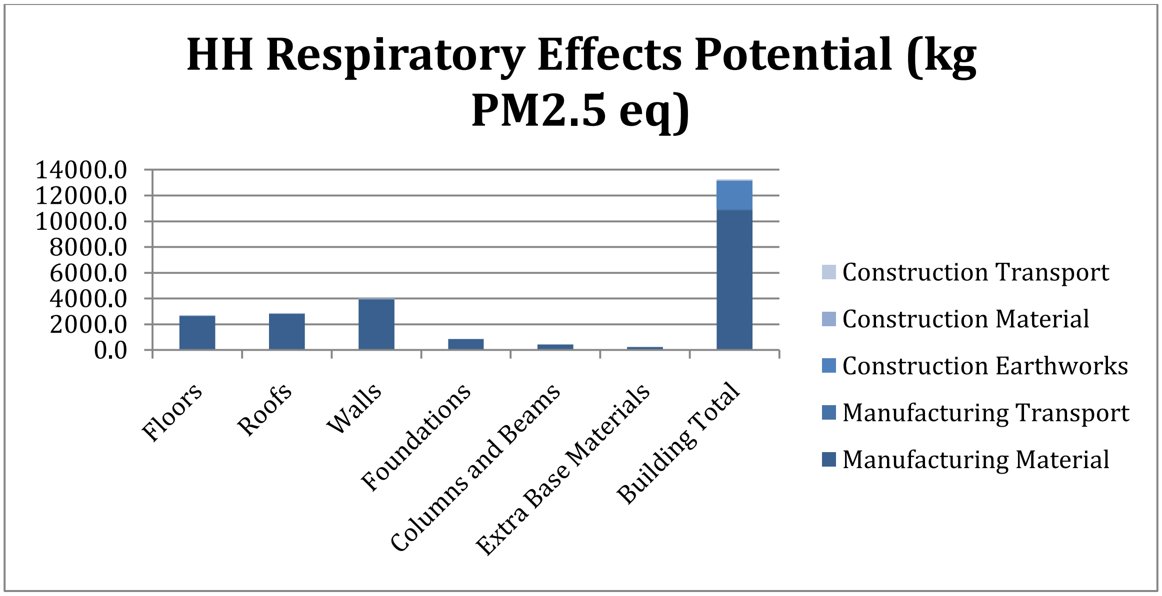

Figure 11 - 5.2.6 Human Health Respiratory Effects Potential

The effect of concrete on this impact category has to do with the amount of particulate matter released during production (same source as above).

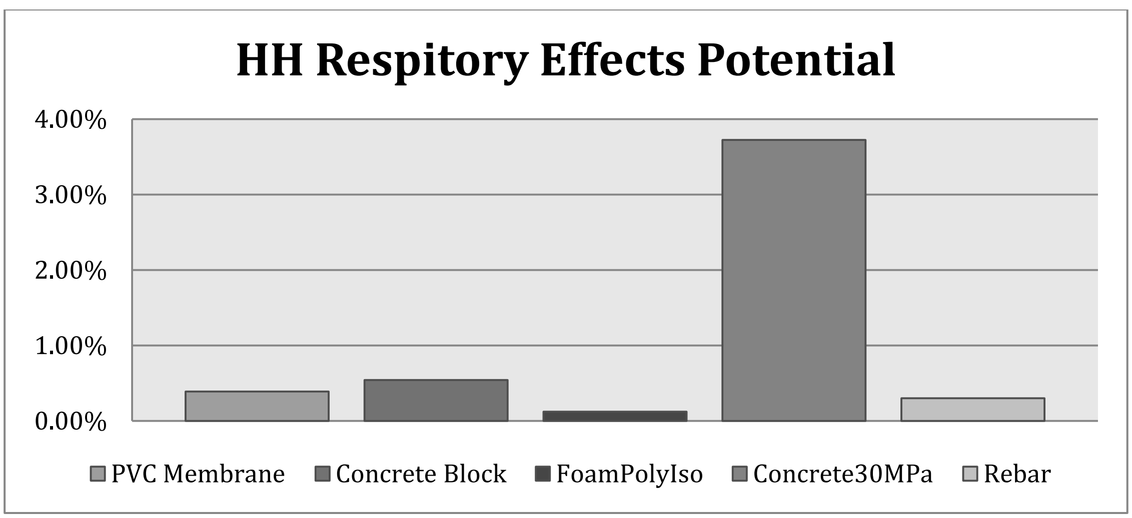

Figure 12 - 5.2.6 Human Health Respiratory Effects Potential Sensitivity Analysis

5.2.7 Weighted Resource Use

Weighted resource use is an impact category characterized by the Athena Institute. Weighted resource use is measured in kilograms weighted by the ecological carrying capacity of a given resources extraction. In weighing resources, Athena considers the intensity of impacts, the extent of the impact area, the duration the impact lasts, and the ecological significance of the impacted area. For example, a kilogram of limestone use is weighted as 1.5 kilograms, while a kilogram of coal is weighted as 2.25 kilograms to reflect its larger impact.

After weighing, 23 million kilograms of resources were used in the manufacture and construction of NTA. Over 99% of this use is in the materials manufacturing stage. The floor assemblies used the most resources at over 9 million weighted kilograms.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roof	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	9127290.3	2775623.7	6218417.4	3365252.7	745711.3	840425.8	23072721.3
	Transport	17053.9	7142.2	12276.2	6303.1	1724.7	1578.3	46078.5
	Total	**9144344.2**	**2782765.9**	**6230693.7**	**3371555.8**	**747436.0**	**842004.1**	**23118799.8**
Construction	Earthworks							274520.0
	Material	16181.5	1258.2	8937.2	1515.7	4.5	0.0	27897.1
	Transport	15679.8	15055.7	14482.7	5031.1	3701.9	1367.4	55318.6
	Total	**31861.3**	**16314.0**	**23419.9**	**6546.7**	**3706.4**	**1367.4**	**357735.6**
Total		9176205.6	2799079.9	6254113.5	3378102.6	751142.4	843371.5	**23476535.4**

Table 8 - 5.2.7 Weighted Resource Use

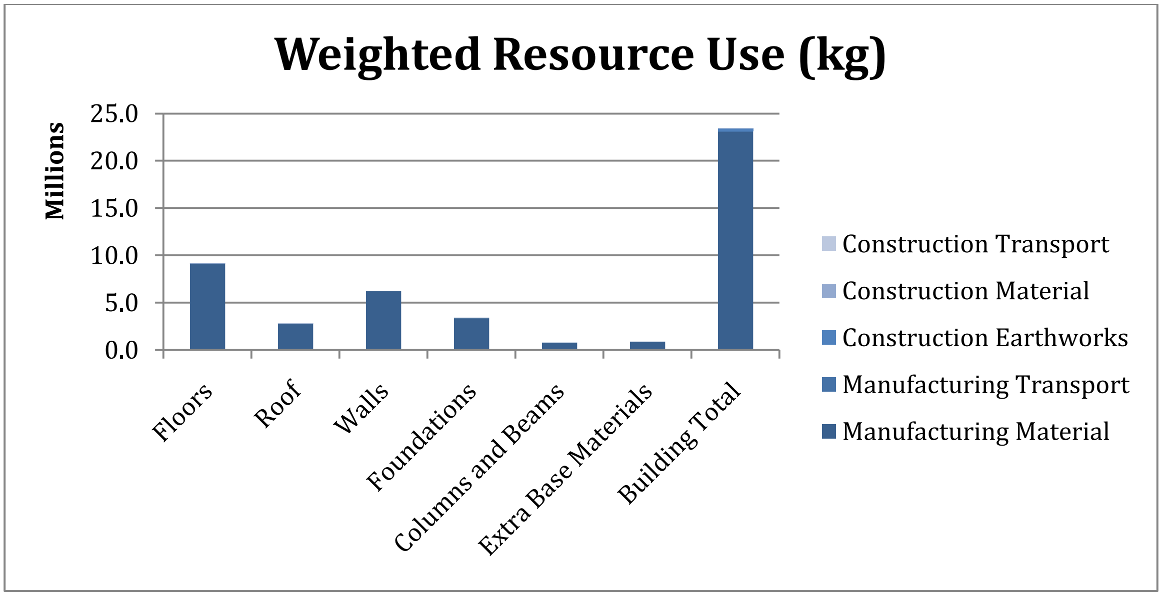

Figure 13 - 5.2.7 Weighted Resource Use

Concrete dominates the weighted use of resources, with all other materials, including concrete block, close to negligible in this category. Clearly the weight of resources extracted that go into the manufacturing and extraction of cement and concrete are significant.

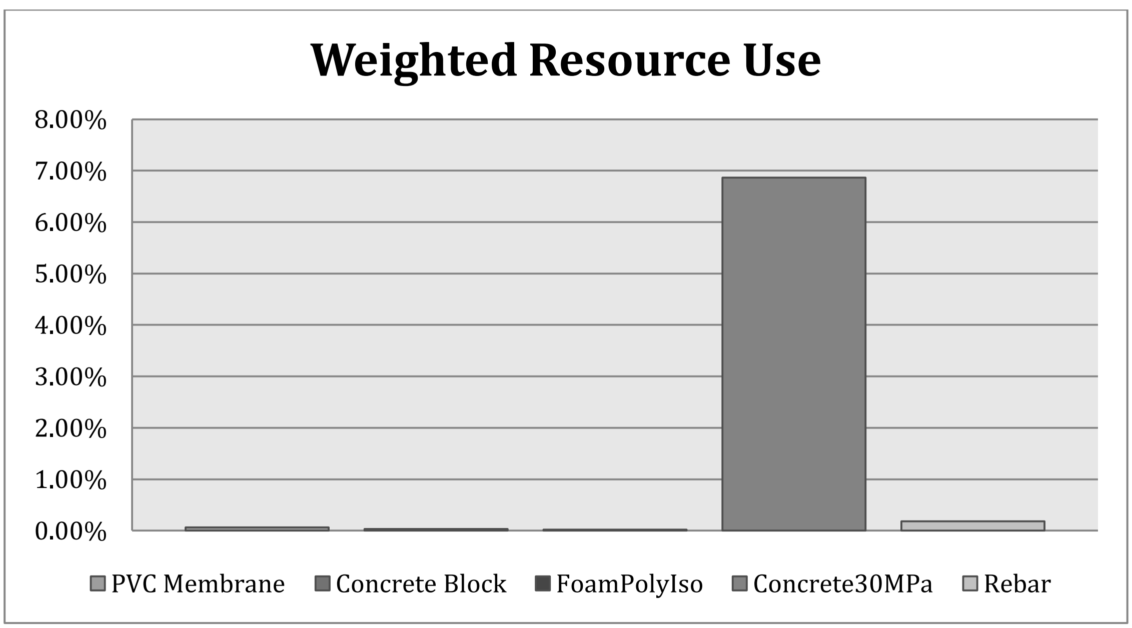

Figure 14 - 5.2.7 Weighted Resource Use Sensitivity Analysis

5.2.8 Fossil Fuel Consumption

Fossil fuel consumption is a sub-category which falls within the Primary Energy Consumption impact category. Fossil fuel consumption is characterized by the Athena Institute and measured in Mega Joules (MJ). This category represents all direct and indirect fossil fuels use in transforming raw materials into a finished product. This includes processing, transporting, converting and delivering fuel and energy.

Over 64 million Mega Joules of fossil fuel were used in the manufacture and construction of NTA. Close to 19 million MJ of this impact was as a result of the roof assemblies. The wall assemblies were responsible for 15 million MJ and the floor assemblies, 13 million MJ.

Life Cycle Stage	Process	Assembly Groups						
		Floors	Roof	Walls	Foundations	Columns and Beams	Extra Base Materials	Building Total
Manufacturing	Material	10907669.2	17944884.5	13232652.7	1819864.5	3755162.9	563424.7	48223658.5
	Transport	505114.4	204105.6	394954.6	183991.1	60054.2	45587.2	1393807.0
	Total	**11412783.6**	**18148990.1**	**13627607.3**	**2003855.6**	**3815217.1**	**609011.9**	**49617465.5**
Construction	Earthworks							11655438.9
	Material	698127.0	54283.8	385566.1	65391.3	183.9	0.0	1203552.1
	Transport	666194.3	640510.9	615286.6	213521.0	158701.5	58106.4	2352320.6
	Total	**1364321.3**	**694794.6**	**1000852.7**	**278912.2**	**158885.4**	**58106.4**	**15211311.6**
Total		12777104.8	18843784.7	14628460.0	2282767.8	3974102.6	667118.3	**64828777.1**

Table 9 - 5.2.8 Fossil Fuel Consumption

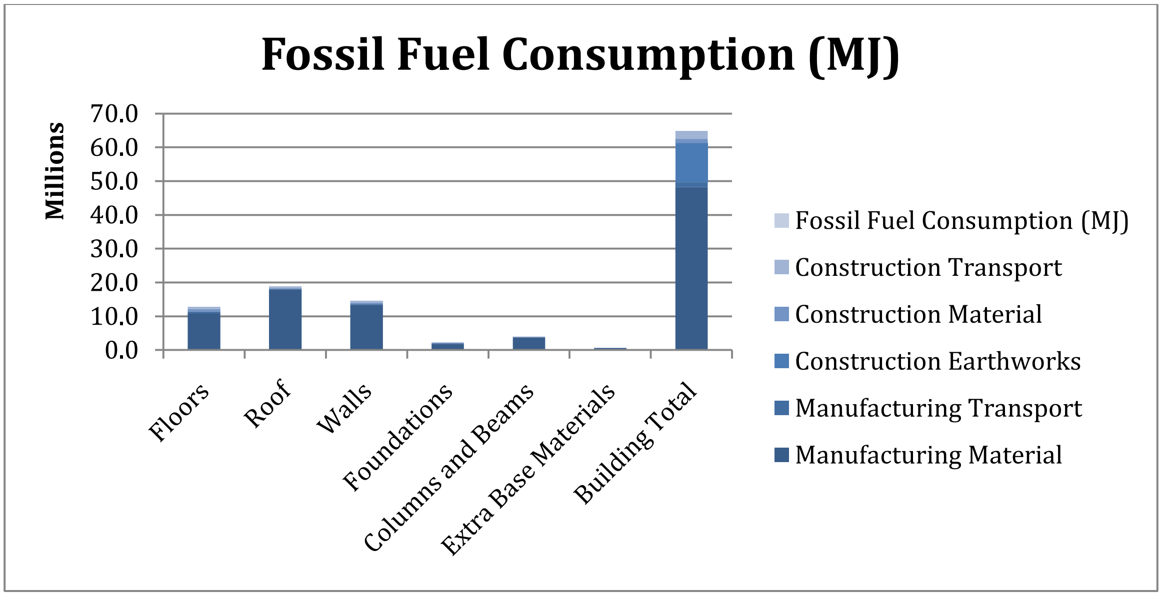

Figure 15 - 5.2.8 Fossil Fuel Consumption

The sensitivity of this category was more evenly distributed among the 5 materials being analyzed. Although concrete still has the largest impact with just over 1.5%, PVC and rebar were both close to 1%, showing the amount of energy that goes into the manufacturing of these materials.

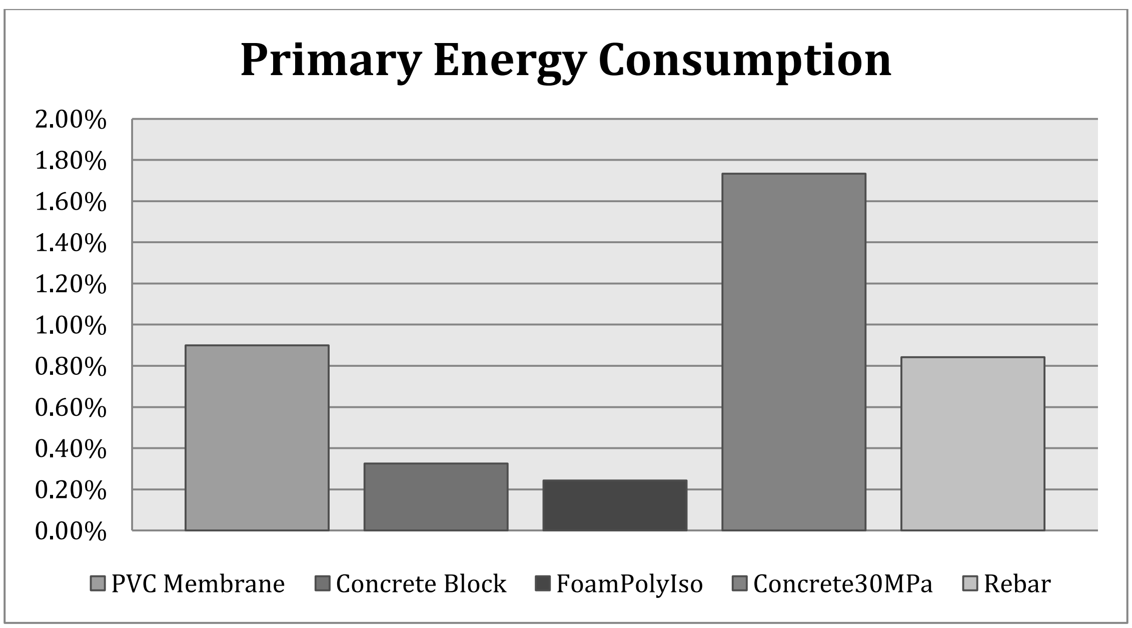

Figure 16 - 5.2.8 Fossil Fuel Consumption Sensitivity Analysis

5.3 Uncertainty

While there is a temptation to view the results of an LCA as absolute or concrete fact given the scientific methodology employed, an overview of the underlying uncertainty in contemporary LCA methods, and more specifically those used in this study, must be included in order for our audience to draw informed conclusions.

5.3.1 Data: Missing or Old

By using the Athena Impact Estimator we have no control over the Life Cycle Inventory Data, and therefore are not able to update it with more current figures. While Athena does its best in keeping its databases up to date, the ever evolving realm of construction materials and practices make this practically impossible. The most recent version of the Impact Estimator (4.1) was released in June of 2010, and between then and January of 2011 there have been 12 updates to the software. However, even with this rapid updating, some materials haven't been updated in a while and there are still many materials not available in the Impact Estimator which were used in the NTA. According to the Athena website (http://www.athenasmi.org/tools/database/structural-db.html) the concrete database was first created in 1993/4 and hasn't been updated since 2006. Additionally the roofing material used for much of the NTA was Thermoplastic PolyOlefin (TPO), a multi-layered membrane applied in strips and 'welded' together to form a single impervious surface. There was no option for TPO in the Athena Impact Estimator because it is such a new material, and therefore a 'best-guess' material (PVC) was chosen instead.

5.3.2 Designed versus As-Built

While we were fortunate enough to have access to the majority of the design and structural drawings for the NTA, as with any construction project there can often be large discrepancies between the building that exists on paper and what actually gets built in the end. The reasons for this can vary greatly, but almost without exception happen on every construction project. It might be due to the unavailability of materials, the contractors unfamiliarity with a particular material, some value-engineering that see design features cut from the building, or change-orders from the building owner due to a change in projected use. Whatever the reason, the room for error between the designed building and the arena as it was constructed certainly exists.

5.3.3 Data Collection

A number of uncertainties arose out of the methods we used for collecting our material inputs from the building drawings. In the case of floors and roofs, uncertainty arises where area takeoffs meet each other, often underneath or above a wall. The exact placement of these takeoffs varies from one to another, especially when the takeoffs are angled. OST functions well for most rooms that aren't bounded vertically and horizontally in the structural blueprints by snapping to set degrees, but some walls in the arena are not at a convenient angle, and so the area takeoff must be zigzagged along the boundary to get the closest approximation of area.

There are also uncertainties that arise from the assumptions made during takeoffs of floors and roofs, particularly when it comes to assembly envelopes. These assumptions are elaborated upon in their respective sections above.

6 Functions and Impacts

In this section, the current and intended uses of the new Thunderbird Arena will be discussed, and the building and different spaces therein will be divided up and classified to estimate the environmental impact potential attributed to each of these functional uses. It should be noted that floor area takeoffs are continuous through walls and are all estimates due to the uncertainty in aligning takeoffs to each other through walls and occasionally at angles not convenient to work with in OST.

6.1 Building Functions

In addition to its service as an Olympic venue and practice centre, the New Thunderbird Arena is intended for continued and future use as an ice rink for games, training and education, and

Functional Use	Square Footage	% of Total
Administration	3,950	1.97%
Seating	33,099	16.51%
Storage	4,445	2.22%
Unassigned	9,580	4.78%
Utilities	9,569	4.77%
Washrooms	11,550	5.76%
Multipurpose Rinks	32,873	16.39%
Walkways/Stairs	77,403	38.60%
Retail/Concession	3,122	1.56%

Ancillary Recreational Use	14,940	7.45%
Grand Total	200,531	100.00%

Table 10 - 6.1 Sectional Percentage of Building Square Footage

also as rental space for concerts, sporting events and other special occasions. Area takeoffs were taken of all the rooms in the facility and labeled according to their use. These were generalized further in accordance with the goal, scope and functional units decided upon at the start of the project. The figure below indicates the results of the area takeoffs and shows the total for each function category. As with the floor takeoffs in section 3, steel and concrete stairs were modeled in addition to any floor underneath. Uncertainties at the edges of the takeoffs are independent of the room type and thus are equally weighted for each area estimate. There are some sections of the building not yet completed for the intended use, but for this model they are labeled according to the intended usage as described in the structural blueprints.

Administrative space consists of offices, meeting rooms and any other rooms associated to these two. Seating consists only of the bleachers in the main rink. Utilities rooms consist of rooms containing mechanical, electrical and plumbing (MEP) systems for the building. “Ancillary Recreational Use” is a description encompassing locker rooms (but not showers) and facilities used by people and athletes when they are not playing on the rinks. The future Hall of Fame in the building has been labeled as administrative use for lack of a better assignment. All other functional areas consist of floor areas labeled as their respective function. In looking at the breakdown of each functional area in this file, it is shown that the large central concourse and curved open spaces at each end of the main rink contribute to such a large amount of space being used for walkways. Also, areas around each rink at grade were assigned to this use as well; though they may come to be used partly as storage or something else, there is no way to tell for sure how the spaces will be broken up except that part of them will always be needed to get from one side of either rink to the other.

6.2 Functional Units

In an environmental impact analysis, the functional unit is the way to quantify the environmental impacts over a value that captures the function of the structure and intent of the LCA. In the case of the New Thunderbird Arena, the building was intended for hockey games and practices during the 2010 Olympics, and for continued use in ice sports and special events afterwards. Keeping in mind these intended uses, it was decided for the New Thunderbird Arena - as well as the other two facilities being analyzed in separate reports - to be broken down in the following ways:

1. Impact potential per generic floor area
2. Impact potential per function-specific floor area
3. Impact potential per number of athletes that can make use of the facility at a given time
4. Impact potential per spectator viewing events in the facility.

The first method is simply to estimate the environmental impact potential over the size of the facility. The second unit is used to gain perspective on what functional uses contribute most to this facility or facilities of this type, though it should be noted that some areas may be more affected by impacts - from walls, changes in floor type, or presence of beams/columns - than this report estimates.

The third functional unit is useful for events where the amount of spectators may be uneven or non-existent compared to how the facility is being used at the time. Likely situations where this method would be most useful would be for sports practices, public skating or low-attendance sports games and tournaments, where several teams are making use of the facilities at once. Estimates for this method are based on the presence of two teams in each ice rink, with a size of 20 players per team for a total of 80 players.

For the fourth point, there is some uncertainty in estimating attendance in the smaller ice rink because spectators watch from the third-floor walkway, where there is no seating. Therefore, spectator estimates will be used based on the capacities provided from the official website, which states capacities of 5054 for hockey and skating, 5800 for concerts and 6500 for graduations/convocations. The effectiveness of this method is more relevant in situations such as concerts, where several rooms may not be used.

Impact Category	Impact value (units in report)	Method 1: Total Floor Area (SF)	Method 2: Functional unit area (SF)									
			Admin.	Seating	Storage	Unassigned	Utilities	Washrooms	Multi. Rinks	Walkways / Stairs	Retail / Concession	Ancillary Rec. Use
Fossil Fuel Consumption	53,173,338	265	1,047,462	8,776,579	1,178,800	2,540,197	2,537,379	923,228,374	8,716,652	20,524,377	827,696	3,961,573
Weighted Resource Use	23,202,016	116	457,057	3,829,632	514,365	1,108,407	1,107,177	402,847,739	3,803,483	8,955,746	361,163	1,728,620
Global Warming Potential	4,093,391	20	80,636	675,639	90,746	195,549	195,333	71,071,985	671,025	1,580,008	63,718	304,970
Acidification Potential	2,175,166	11	42,849	359,024	48,221	103,912	103,797	37,766,580	356,573	839,592	33,859	162,056
HH Resp. Effects Potential	13,149	0.07	259	2,170	292	628	627	228,308	2,156	5,076	205	980
Eutrophication Potential	2,469	0.01	49	408	55	118	118	42,874	405	953	38	184
Ozone Depletion Potential	4.14E-03	2.06E-08	8.16E-05	6.83E-04	9.18E-05	1.98E-04	1.98E-04	7.19E-02	6.79E-04	1.60E-03	6.44E-05	3.08E-04
Smog Potential	17,270	0.09	340	2,851	383	825	824	299,852	2,831	6,666	269	1,287

Table 11 - 6.2 Impact Potential for Area-Based Functional Units

Impact Category	Impact value (units in report)	Method 3: Athletic use	Method 4: Attendance at hockey (5,054), concerts (5,800) or graduation (6,500)		
		Per 80 hockey players	Hockey	Concert	Graduation
Fossil Fuel Consumption	53,173,338	664,667	10,521	9,168	8,181
Weighted Resource Use	23,202,016	290,025	4,591	4,000	3,570
Global Warming Potential	4,093,391	51,167	810	706	630
Acidification Potential	2,175,166	27,190	430	375	335
HH Resp. Effects Potential	13,149	164.37	2.60	2.27	2.02
Eutrophication Potential	2,469	30.87	0.49	0.43	0.38
Ozone Depletion Potential	4.14E-03	5.18E-05	8.19E-07	7.14E-07	6.37E-07
Smog Potential	17,270	215.88	3.42	2.98	2.66

Table 12 - 6.2 Impact Potential for Attendance-Based Functional Units

7 Conclusions

The life cycle assessment of the New Thunderbird Arena was performed by conducting a detailed quantity take off of all building materials, then transferring these quantities to the Athena Impact Estimator. Using the Impact Estimator, and estimate was obtained for eight impact categories for the building as a whole and each was broken down by assembly group. Due to the nature of LCA and the realities of data availability, assumptions were made at several stages in the process. Wherever possible, these assumptions were taken into account in the analysis, and all assumptions were documented.

Five of the most used materials included PVC membrane, concrete blocks, foam polyisocyanurate, 30MPa concrete and steel rebar. A sensitivity analysis revealed that a 10% change in the quantity of concrete had the largest effect in most impact categories. The wall, floor and roof assemblies created the most impact in most categories, due to their sheer size. By far, the manufacturing of materials contributed the most impacts of all life cycle stages at over 90% for all categories.

In total, more than 4.8 million kilograms of CO_2 equivalent were released. Weighted resource use topped 23 million kilograms and fossil fuel consumption was in excess of 64 million MJ. Earthworks contributed the most to the human health respiratory effects and the acidification potential impact categories. Transportation effects were most visible in the smog potential category.

Ideally, in the future similar studies should be conducted on other UBC buildings or sports facilities and comparative assertions conducted. Additionally, as this study only considered the effects associated with the manufacturing and construction of NTA, operating energy, maintenance, and end-of-life impacts were not considered and offer potential for future study.

8 Appendix A – Additional Tables and Figures

Construction Material	Units	Assembly Group						Building Total
		Foundation	Walls	Floors	Columns and Beams	Roof	Extra Materials	
Concrete Blocks	Blocks	x	81450.2	x	x	x	x	81450.2
Ballast (aggregate stone)	kg	x	x	x	x	699846.7	x	699846.7
PVC membrane	kg	x	x	x	x	57534.4	x	57534.4
EPDM membrane (black, 60 mil)	kg	x	316.7	x	x	x	x	316.7
Water Based Latex Paint	L	x	360.1	x	x	x	x	360.1
6 mil Polyethylene	m2	x	x	5242.5	x	11330.9	x	16573.3
1/2" Moisture Resistant Gypsum Board	m2	x	x	x	x	12539.7	x	12539.7
1/2" Gypsum Fibre Gypsum Board	m2	x	2773.8	x	x	x	x	2773.8
1/2" Fire-Rated Type X Gypsum Board	m2	x	2646.7	x	x	x	x	2646.7
Standard Glazing	m2	x	302.8	x	x	x	x	302.8
Softwood Plywood (9mm)	m2	x	x	x	x	226.0	x	226.0
Batt. Fiberglass (25mm)	m2	x	42.9	x	x	x	x	42.9
Foam Polyisocyanurate (25mm)	m2	x	7363.9	15431.8	x	x	x	22795.8
Isocyanurate (25mm)	m2	x	x	x	x	17463.5	x	17463.5
Blown Cellulose (25mm)	m2	x	x	4453.7	x	x	x	4453.7
Oriented Strand Board (9mm)	m2	x	1104.9	x	x	x	x	1104.9
Concrete 30 MPa (fly ash 35%)	m3	1315.6	1153.7	2882.5	x	x	320.3	5672.0
Mortar	m3	x	1554.3	x	x	x	x	1554.3
Concrete 30 MPa (fly ash av)	m3	x	x	395.3	121.3	x	x	516.6
Small Dimension Softwood Lumber, kiln-dried	m3	x	x	x	x	24.2	x	24.2
Concrete 30 MPa (fly ash 25%)	m3	x	23.5	x	x	x	x	23.5
GluLam Sections	m3	x	x	x	23.2	x	x	23.2
Open Web Joists	Tonnes	x	x	169.6	x	478.2	x	647.7
Rebar, Rod, Light Sections	Tonnes	8.6	421.3	76.0	57.1	x	x	563.0
Galvanized Decking	Tonnes	x	x	42.3	x	114.2	2.1	158.6
Wide Flange Sections	Tonnes	x	x	x	80.7	x	x	80.7
Hollow Structural Steel	Tonnes	x	x	x	43.1	x	3.7	46.8
Joint Compound	Tonnes	x	5.4	x	x	12.5	x	17.9
Welded Wire Mesh / Ladder Wire	Tonnes	x	x	14.1	x	x	x	14.1
Aluminum	Tonnes	x	9.0	x	x	x	x	9.0
Glazing Panel	Tonnes	x	7.8	x	x	x	x	7.8
Screws Nuts & Bolts	Tonnes	x	0.3	x	5.3	x	x	5.6
Galvanized Sheet	Tonnes	x	1.9	x	x	3.7	x	5.6
Galvanized Studs	Tonnes	x	3.5	x	x	x	x	3.5
Nails	Tonnes	x	0.7	0.6	x	1.3	x	2.5
Paper Tape	Tonnes	x	0.1	x	x	0.1	x	0.2

Table 13 - A.1 Bill of Materials

9 Appendix B

IE Inputs Document

10 Appendix C

IE Assumptions Document