# Life Cycle Assessment Report

# Thunderbird Old Arena

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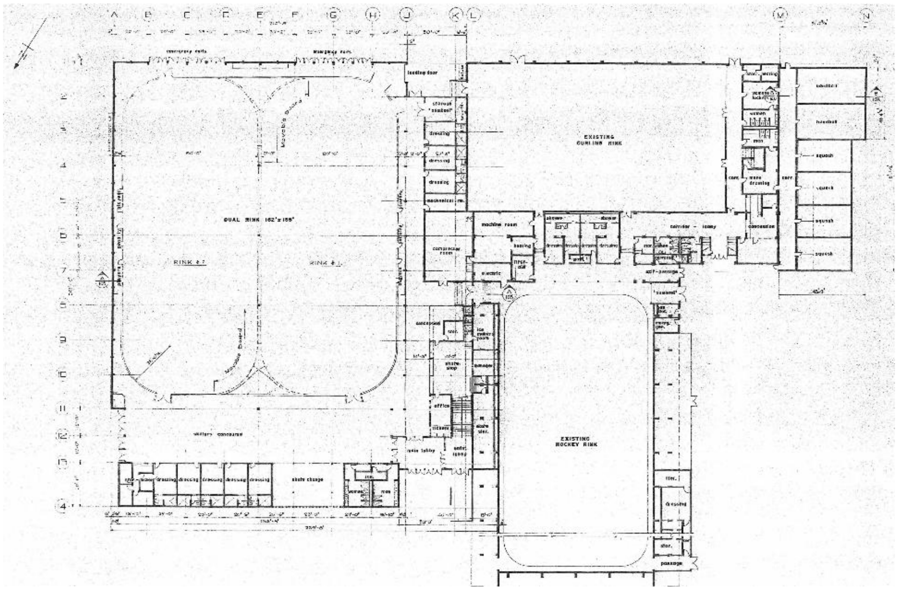
**CIVL 498C**

**March 24, 2011**

# PROVISO

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.



# CIVIL 498C: Life Cycle Assessment Report

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| Submission Date: | March 24, 2011 |
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# ABSTRACT

Prior to the 2010 Vancouver Winter Olympics several structures were built for recreational purposes. A life cycle assessment (LCA) was carried out on two of the event arenas built for the 2010 Winter Olympics. One of the sites, the Thunderbird Arena was a renovation of an existing recreational complex. The LCA presented in this report is for the pre-existing complex, which consists of three main buildings.

The scope focuses on the materials manufacturing and the construction of the buildings (i.e. maintenance and usage are disregarded) and the results were used to compare the impacts of the materials used during construction to aid with future design decisions. Modeling was conducted using On-Screen Takeoff 3 and Athena Impact Estimator (IE) software. These tools allowed for a Bill of Materials (BoM) to be generated as well as characterisations of the total environmental impacts due to materials manufacturing, building construction, and transportation. The TRACI method was used to report values on fossil fuel consumption, weighted resource use, global warming potential, acidification potential, human health respiratory, eutrophication potential, ozone depletion, and smog potential.

It was found from the BoM that the top 5 materials used during the construction were aggregate rock, rebar, galvanized sheeting, steel tubing, and concrete block. A sensitivity analysis was then run on the materials to determine the change in impacts based off a 10% increase in each case. It was found that the most significant change in impact on construction was the 10% increase in rebar.

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# 1.0 INTRODUCTION

## Background

The original Thunderbird Arena, located on the University of British Columbia Campus at 2555 Wesbrook Mall, was constructed in 1962 under the direction of A.B. Sanderson and Company LTD. The initial build consisted of two main buildings housing a full-size hockey rink (Father Bauer Arena) with 900 permanent seats, a curling complex and the associated amenities (locker rooms, skate shop, etc.) This original complex is notable in that it was the birthplace of Canada's first national hockey team in 1963. The complex was expanded in 1968, this time under the direction of Phillips, Barratt, Hillier, Jones and Partners. This was a fairly significant expansion, adding two additional full-size ice rinks, squash and handball courts, further amenities and an enhanced lobby area.

Construction commenced on the new Thunderbird Arena in April of 2006, bringing with it the demolition of the majority of the original sports complex. Though it was refurbished, the Father Bauer Arena still remains as part of the new complex. During the 2010 Olympic Games, the Father Bauer Arena was used as practice ice and it will continue to play a central role in the campuses community and educational programs.

## Building Characteristics:

| | |
|---|---|
| **Structure** | Concrete and steel columns supporting concrete suspended slabs |
| **Floors** | Ground Floor: Concrete slab on grade; First Floor: Suspended slab |
| **Exterior Walls** | 8" Concrete block with several smaller sections of cast-in-place walls |
| **Interior Walls** | 8" and 6" Concrete block construction with some wood stud partitions |
| **Windows** | All windows assumed to be standard glazing |
| **Roof** | Built-up roofs, Glulam and steel trusses |

# 2.0 GOAL AND SCOPE

## *2.1 Goal of Study*

This life cycle assessment (LCA) of the Old Thunderbird Arena at the University of British Columbia was carried out as an exploratory study to determine the environmental impact of its design. This LCA of the Old Thunderbird Arena is one study in a series being carried out on Olympic venues in the Greater Vancouver Regional District, including the Richmond Oval and the Thunderbird Winter Sports Complex.

The main outcome this LCA study is to establish a materials inventory and to provide environmental impact references for the Old Thunderbird Arena. An exemplary application of these references is the establishment of a benchmark for evaluating the relative performance of future Olympic venues. When this study is considered in conjunction with the Richmond Oval LCA and the Thunderbird Winter Sports Complex LCA, further applications include the possibility of carrying out environmental performance comparisons across Olympic area venues, renovation versus new construction. In the case of the Thunderbird Winter Sports Complex, to compare UBC buildings over time with differing materials, structural types and building functions. Furthermore, as demonstrated through these potential applications, this Old Thunderbird Arena LCA can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future Olympic and UBC construction, renovation and demolition projects.

The intended core audience of this LCA study is made up of the International Olympic Committee (IOC), future Olympic host cities and the UBC Vancouver campus. Other potential audiences include the general public, developers, architects, engineers and building owners involved in design planning, as well as external organizations such as governments, private industry and other universities whom may want to learn more or become engaged in performing similar LCA studies within their organizations.

## *2.2 Scope of Study*

The product systems being studied in this LCA are the structure and envelope of the Old Thunderbird Arena on the basis of generic floor area, function specific floor area, competition capacity and spectator capacity. 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 the construction of the structure and envelope of the Old Thunderbird Arena, as well as associated transportation effects throughout.

## *2.3 Tools, Methodology and Data*

Two main software tools were utilized to complete this LCA study; OnCenter's On-Screen Takeoff 3 and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings.

The study first reviewed the initial stage of a materials quantity takeoff, which involved performing linear, area and count measurements of the building's structure and envelope. To accomplish this, On-Screen Takeoff version 3.7.0.12 was used, a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. Using imported digital plans, the program simplified the calculation and measurement of the takeoff process, while reducing the error associated with these two activities. The generated measurements were formatted into the inputs required for IE building LCA software to complete the takeoff process. These formatted inputs as well as their associated assumptions can be viewed in Appendices A and B respectively. The engineering and architectural drawings needed to complete this portion of the study were provided by the UBC Records Department.

Using the formatted takeoff data, version 4.1.12 of IE software was used to generate a whole building LCA model for the Old Thunderbird Arena in the Vancouver region as a commercial building type to reflect its various functions. IE software is designed to aid the building community in making more environmentally conscious material and design choices. The tool achieves this by applying a set of algorithms to the recorded takeoff data in order to generate a bill of materials (BoM). This BoM then utilizes the Athena Life Cycle Inventory (LCI) Database, version 4.6, in order to generate a cradle-to-grave LCI profile for the building. In this study, LCI profile results focus on the manufacturing and transportation of materials as well as their installation in the initial structure and envelope assemblies. The service life in IE was set to 1 years; however, as maintenance and operation costs are considered to be outside of the project scope, this is equivalent to looking at the building in terms of a one-year service life. As this study is restricted to a cradle-to-gate assessment, the end-of-life stages of the building's life cycle are also ignored. Therefore, the superficial decision to leave the service life at 1 years was made to reflect, in some way, that a portion of the original arena remains in operation.

IE then filters the LCA results through a set of characterization measures based on the mid-point impact assessment methodology developed by the US Environmental Protection Agency (US EPA), the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), 2007 version. In order to generate a complete environmental impact profile for the Old Thunderbird Arena, all of the TRACI impact assessment categories available in 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
- Fossil fuel consumption

Using the summary measure results, a sensitivity analysis was then conducted in order to reveal the effect of material changes on the impact profile of the Old Thunderbird Arena.

The primary sources of data for this LCA were the original architectural and structural drawings from when the Old Thunderbird Arena was initially constructed in 1962 and expanded in 1968. The assemblies of the building that were modeled include the foundation, columns and beams, floors, walls and roofs, as well as the associated envelope and openings (i.e. doors and windows) within each of these assemblies. The decision to omit other building components, such as flooring, electrical aspects, HVAC system, finishing and detailing, etc., is associated with the limitations of available data and IE software. In the analysis of these assemblies, some of the drawings lack sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in IE software. Furthermore, there were inherent assumptions made by IE software in order to generate the BoM and limitations to what it could model, which necessitated that further assumptions be made. These assumptions and limitations will be discussed further in the Building Model section and, as previously mentioned, all specific input related assumptions are contained in the Input Assumptions document in Appendix B.

# 3.0 BUILDING MODEL

The purpose of this section is to establish how the model of the building was developed, where the major challenges were encountered, and what assumptions were made in modeling the individual building components.

## *3.1 Takeoffs*

The takeoffs were done using On-Screen Takeoff 3. The software allows for three different modeling conditions; area conditions, linear conditions and count conditions. Area conditions were used for plan view area takeoffs such as roofs, floors and extra basic materials. For example, several area conditions were created to account for each component in half a truss. Afterwards, each condition was used to find the total amount of material in one complete truss.

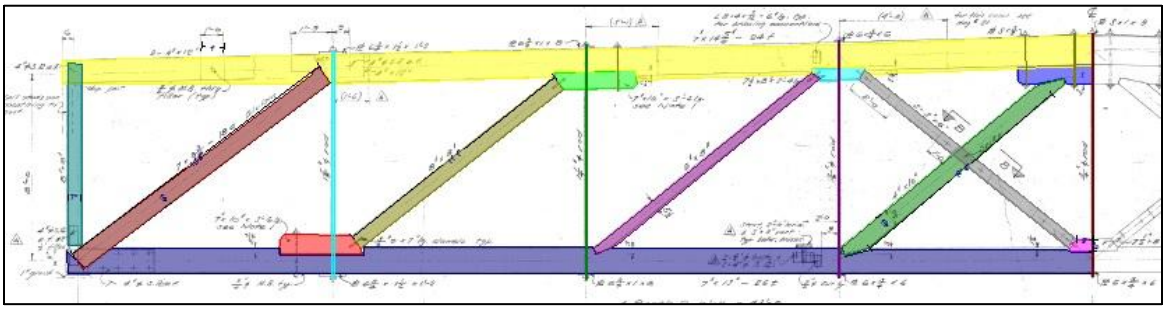


**Figure 1- Separate area conditions (denoted by varied colours) used to find the total amount of  in one truss**

Linear conditions were appropriate for finding wall or strip footing volumes. On-Screen calls for two inputs- height and thickness- then the user is able to trace the linear feet using On-Screen tools (Fig.2). Count conditions were useful for modeling repetitious entities with similar properties (i.e. doors, windows, footings, columns and beams). The user defines the volumetric properties of one object and then the user can click on all of the defined objects to record how many are in the building.

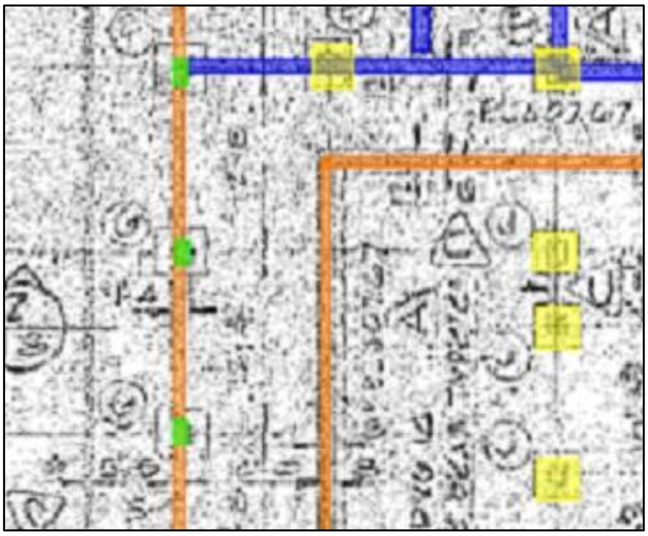


**Figure 2- Strip footings being modeled with a linear conditions (orange and blue) and footings being modeled with count conditions (yellow and green)**

Furthermore, a nomenclature was designed for the project to help with the organization and readability of the inputs. Assemblies were defined as foundations, walls, columns/beams, floors, roofs and extra basic materials. Within these assemblies a nomenclature was assigned to every material that was modeled. For example, extra basic material would be documented like this:

**XBM_**(*insert assembly descriptor, i.e. columns,stairs)_(insert where materials are coming from)_(insert material type)_(insert additional descriptors)*

The logic behind this nomenclature was used to organize the inputs and assumptions document that was compiled for the report. With the outlined nomenclature, it is much easier to organize the collected information for referencing purposes.

Major challenges with the modeling included an incomplete drawing package and the poor quality of said drawings, which made it difficult to read notes and identify the locations of certain building attributes. Furthermore, the majority of the building no longer exists, limiting on-site research. This resulted in assumptions that are mentioned in the following sections as well as in Appendix B.

## 3.2 Modeling Assumptions

Assumptions were necessary to model the Old Thunderbird Arena based on the fact that some of the buildings no longer exist and therefore could not be visited for reference. Also, the drawings provided were missing information or were difficult to view due to the scanning and condition of the original drawings. The two drawing packages that were available for review included drawings from the original building on the site from 1962 and the expansion that took place in 1968, which included renovations and the addition of a new arena.

### ***Footings***

In order to model the footings in the expansion drawings, adjustments to the modeled shape of the footings were made. Irregular shaped footings, defined as having a wide base and smaller pedestal, were modeled by adding the volume of the vertical section (pedestal) of the footing to the thickness of the base with the same length and width dimensions as the base. Due to limitations in the IE, the thickness has a maximum input value of 19.7 inches. Any footings that had thicknesses over this value had the additional thickness added to the width to create a like-volume footing. After all footings were accounted for in On-Screen Takeoff, the number of footings was multiplied by the width in order to account for all of the material used to construct the footings. The process used to count the footings in On-Screen Takeoff is illustrated in the diagram below:

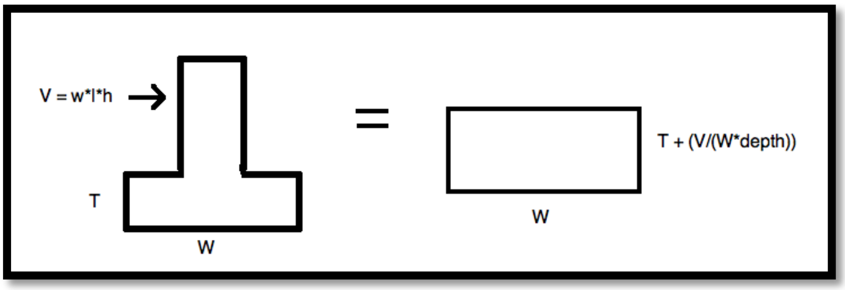


**Figure 3: How footings were modeled in Impact Estimator**

Assumptions for the footing material were that the rebar was typically #6 unless specifically marked otherwise. Most of the rebar was listed at higher than #6 which may lead to a low estimate in the amount of rebar. Again, this was due to limitations in the maximum rebar size in IE.

The concrete stairs and concrete stands were modeled in IE as footings under the assumption that they had similar constructions. The width of the stairs was measured and then the area of the cross section of the stairs was determined in order to find the total volume. The volume was then converted to a cube with a thickness of 19.7 inches and modeled as a footing. The structural drawings for the stairs were not available so it was assumed that the concrete was 3000 psi and the rebar was #6. Some of the cross-sections of the stairs were also not depicted in drawings so assumptions were made based on the measured width and number of stairs to model the cross section from other staircases in the building.

### ***Columns and Beams***

The concrete columns for the twin arena from the 1968 expansion drawings were modeled according to IE Method 1 under mixed column and beams. It was assumed that the bay size and suspended span could be measured from the corner of the arena where the vertical and horizontally located columns meet, as shown in the figure below. Although the columns in the arena were not centrally located as shown in the figure, the set number of columns in the arena, calculated in On-Screen Takeoff as a count, would be modeled correctly using this method. It was also assumed that the columns support a live load of 50 psf based on the fact that the columns were supporting the roof.

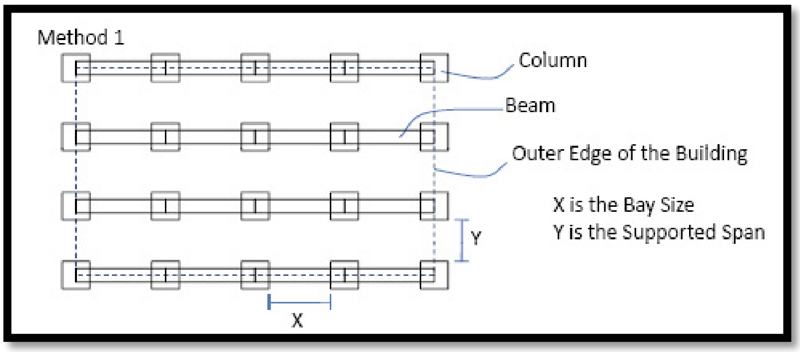


**Figure 4: How columns were modeled for the twin arena where there are no centrally located columns**

The beams were modeled separately so the "number of beams" in the "mixed columns & beams" section in IE was left blank. One type of beam in the twin arena (from the expansion in 1968) was concrete and located on top of the columns around the perimeter of the arena. It was assumed that the beams were similar to footings for lack of other information in the drawings and were modeled as such. Although this may cause an over estimation in rebar if not as much rebar is actually used in these beams, this helped make up for some of the rebar lost in the footings where IE could not meet the rebar requirements as defined in the drawings.

There were also steel columns located in the expansion portion of the arena. The cross sections and thickness of the columns were defined on the drawings and most of the heights were calculated from the drawings. In some cases the heights were assumed based on the location within the building and the height of the roof or floor above. The columns were entered into IE as an extra basic material as they were not uniform throughout the building. The density of the steel was assumed to be 0.245 tons/ft3 and used to calculate the mass of steel in the columns.

In drawing EXP-68-6842-208B, all steel beams were modeled as extra basic materials. Some of the beams possessed a dated reference method and were converted to wide flange (WF) equivalents. For example, some steel beams were denoted with “X-B-Y” convention (12B14 or 10B11.5). 12B14 was assumed to be 12x14 WF and 10B11.5 became 10x12 WF.

To accommodate for the lack of a beam input in the “mixed columns & beams” section the trusses that were outlined in drawing OLD-62-1131-19B were modeled as extra basic materials. Given the complicated geometry of the trusses each component (truss webs, chords, etc) was modeled separately as a volume. Since the drawing only shows half of a truss, the total value was then multiplied by 2 (i.e. full truss) then multiplied by the number of trusses to find the total amount of Douglas Fir in all of the trusses of that type.

### ***Roofs***

Roofs were modeled to the best of the ability of the IE software. In cases where the spans of the roof were greater than the maximum span allowed by IE, the maximum span was used and the width of the roof was calculated based on the Area condition derived from On-Screen Takeoff. Since the loads were not specified in the design drawings, 50psf was assumed to satisfy snow loads and 100 psf assumed for areas of the roof supporting machinery. The envelope of the roof was assumed to be “4-ply built up asphalt – inverted roof assembly”; based on site photographs of the building before demolition. Where drawings specify specific plywood thicknesses, an area of 3/8” Oriented Strand Board (OSB) was calculated to equate the volume of plywood required.

IE models Glulam Joist roofing according to the span of the roof. The beam depth varies with different span and loading conditions. Actual spans were measured in On-Screen using the distance between two columns, and since 38mm SPF T&G are included in the model, no extra material for T&G decking was added. However, in cases where plywood was used, OSB was modeled as aforementioned.

“Open Web Steel Joist with Metal Deck Roof System” was used to model canopies of the newer expansion as specified in the design drawings. Concrete topping is assumed to be excluded since it is not called out in design. For the envelope of the canopies and overhangs, built up roof systems and commercial steel roofing systems were used in modeling, to satisfy callout design.

For the larger spanning roofs, such as the ones in the old curling and hockey arena, truss systems were used that could not be modeled in the IE. XBM calculations of OSB were used to model the plywood decking, and volumes of 8mm galvanized steel was used to assume the actual construction of the roofing system.  In all cases where built up roofing was used, the IE required the input of filler material with a minimum depth of 1”. Therefore, cellulose, organic felt sub was entered as the default and a nominal value of 1” was assumed.

### ***Floors***

In all instances of ground floor modeling, the floor was assumed to be slab on grade. Detailed calculations were made for the twin rinks in the expansion accounting for the volume of PVC piping and rebar in the 5” slab of the ice arena. During these calculations, overlap of rebar was not considered and pipes were assumed to be 1” outer diameter. The decision to make precise estimates of the expansion arena was made based on the detail of the design specifications provided. In the old arena, the slab was modeled to be 4” slab on grade, since the IE only allows the modeling of either 4” or 8” slab thicknesses. The unorthodox design in the old hockey arena (from 1962 construction) calling for a 3’ gravel fill was used to model the curling arena fill due to the lack of design information. The specifications and modeling of the curling arena were assumed to be identical to the hockey arena.

Where suspended slab flooring was modeled, the span of the slab was assumed to be that of the most common column spacing in the area. Where flooring was not specified in the design, it was assumed that the floor was bare concrete, and where Pine T&G Decking is specified, “Pine T&G Cladding” in Extra Basic Material was used, based on the area calculation of the floor. Modeling of the handball and squash courts expansion required assumptions to made, in particular, the type of wood used in the wooden floor. It was assumed that the risers were parallel strand lumber; the sleepers - softwood plywood and the actual flooring pieces - laminated veneer lumber. These assumptions were made based on wood grain orientation and internet research.

### ***Walls***

The walls of the Old Thunderbird Arena are of two main types: concrete block and wood stud, with several cast-in-place sections and a single steel stud exterior wall. All drawings are lacking a significant number of details relating to the walls, although the 1962 drawings are worse. Wall heights and floor elevations are not, for the most part, called out on the drawings and several exterior wall sections follow unspecified slopes. Additionally, few section drawings in either drawing set agreed with each other, sometimes varying by more than a foot of height. Due to these omissions and oversights, most wall heights are estimated and computed from the averages across common section views and the elevation drawings. In the case of slopes and elevation changes (in both the roofline and ground level), either a single wall height was computed based on a midpoint average over the length of the slope. In minor cases (such as stairs and access ramps) the elevation change was treated as a sudden “jump” occurring at the midpoint of the obstacle. Additionally, wall rebar is not detailed outside of two ‘typical’ wall drawings and is therefore assumed to be #4 throughout.

### ***Concrete Block Walls***

Concrete block walls constitute the majority of walls in the Old Thunderbird Arena, with the exception of the squash and handball courts add-on from the 1968 expansion. IE assumes a standard 200 x 200 x 400 (mm) hollow block. The depth of the assumed concrete block matches with the majority of the block walls. The 6” concrete block walls were not re-dimensioned to fit the standard block size as this would skew the amount of steel that IE calculates for the wall and the number of 6” block walls was not significant. The blocks used in the Old Thunderbird Arena are specified as concrete filled, though IE does not have the capability to account for this fill material (additionally, core dimensions of blocks are not specified so that the raw concrete fill volume cannot be calculated with any accuracy).

### ***Cast-in-Place Walls***

There were relatively few cast-in-place walls used in the construction of the Old Thunderbird Arena; however, for the few that were identified, average concrete fly ash and 15M rebar was assumed. Additionally, concrete strength was assumed based on the wall’s location and function. Non-load bearing walls were assumed to be of 20MPa strength, while load bearing walls were assumed to be of 30MPa strength.

### ***Wood Stud Walls***

Wood stud walls were more prevalent in the 1968 expansion than in the original 1962 build and are most prominent in the squash and handball courts. IE handled the wood stud walls relatively well, and the drawings tended to pay more attention to these details. The ‘Wall Type’ of bearing or non-bearing had to be inferred from the wall’s location and function. Additionally, all wood was assumed ‘kiln-dried’ for its greater ease-of-use in construction. Whenever certain details for a wall were omitted, it was assumed that the wall was designed in a similar fashion to those surrounding it.

### ***Envelope***

Envelope information in the 1968 expansion drawings contained adequate detail and, and therefore, was able to be modeled as-drawn. The 1962 drawing set, however, omits most of the envelope details and it is speculated that several wall-schedule drawings were not included in the supplied drawing set. Due to this limitation, envelopes were not considered where they were not explicitly called out on the drawings. In the few cases where a wood cladding of a wood type not available in IE, the wood type was assumed to be Cedar due to the large amount of Cedar already detailed as cladding. Finally, it was necessary that Weyerhauser P15 and other metallic claddings were assumed to be Commercial Steel Cladding (26 Ga.) in IE. Plexiglas derivatives had no equivalent available in IE and were therefore omitted due to their insignificant quantities.

### ***Doors and Windows***

The door schedule was missing in both drawing sets and the door material was inferred from its function if details were not given in the drawings. Any doors called out as aluminum was modeled as Aluminum Exterior Door, 80% Glazing. All interior doors not leading to mechanical rooms or team locker rooms were assumed to be “Hollow Core Wood Interior Doors”, while those leading to team rooms and mechanical rooms were assumed to be “Steel Interior Doors”. Similarly with windows, glass type was rarely detailed and in most cases Standard Glazing was assumed. Window frames were usually detailed on the drawing, but those that were left out were assumed to be Aluminum, as majority.

### ***Earthworks***

The earthworks section required assumptions due to lack of data. Drawing EXP-68-6842-201C provided information on the amount of material removed for the construction of the twin rinks, but the remaining site preparation drawings were not available. In order to find the remaining material removed for the rest of the building, the square footage of the remaining construction area was multiplied by a height of 7.5’ to find the volume of material removed. The LCI data was based on a Road LCA from Sweden. The inputs required were the excavation class, fixed volume excavated and the swelling factor. “Medium- compact soil”, “hard clay”, “gravel”, “less than 25% stone-” was chosen as the excavation class. The fixed volume calculated was 19745.58 cubic meters and a swelling factor of 1.17 (soil with sand and gravel mixed) was chosen for the removed materials. A TRACI characterisation method was used on the data to determine impact assessment results.

### ***Extra Basic Materials***

The wood stairs had very little design information, as the full drawing package was not available. It was assumed that the main frame of the stairs was made of 2X6 dimensional softwood lumber. The width of the stairs was measured off the drawings and the stairs were modeled as an extra basic material using the count function with 2X6 lumber the same width as the stairs.

The fire escape staircase was also modeled as an extra basic material. Assumptions on steel type and thickness were made based on online data for similar staircases, with 11 gauge galvanized steel with a density per unit length of 25.18 kg/m$^2$. The stair case cross section was traced and converted to a total mass and entered as XBM.

The steel in the trusses was also modeled as an extra basic material and was modeled much like the Douglas Fir in the trusses. Using OST, a volume take off was performed on all metal in half of a truss, multiplied by two and multiplied by the number of trusses. The total weight, in tons, was input into the nuts and bolts section in IE.

The complete IE Input Assumptions Document is located in Appendix B, which is the companion document to IE Input Document located in Appendix A. For more detailed description on the assumptions made, including calculations and rationale, please refer to this documentation.

# 4.0 RESULTS AND DISCUSSIONS

This section outlines the main findings from the building model and the impacts measured from the assessment of each assembly in the building. The uncertainty in the modeling process is discussed and a sensitivity analysis is used to establish how changes in the building material correlate to the impacts.

## *4.1 Bill of Materials*

The largest amount of material was ballast (aggregate rock) and was sourced mainly from the floors (Slab on Grade) and roofing (inverted roof). The second highest mass of material was rebar rod, which was contributed mainly by the floors and walls, but includes some additions from columns/beams and the foundations. The third highest source of material was galvanized sheeting, and stems mainly from the roofing of the old curling and hockey arenas. It should be noted that the thickness of the galvanized sheet was assumed to be 8mm and has a direct effect on the mass of the estimate. Ranked fourth by mass was steel tubing, which was used to model the steel columns in the expansion building. Finally, concrete blocks also ranked high in total count, resulting in a high mass, and is contributed wholly by concrete block walls.

An analysis on the sensitivity of the results from a 10% increase in the top five materials will be presented in subsequent sections.

The following table tabulates the total materials in the building and breaks down the source of each material:

**Table 1: Bill of Materials**

| Material | Quantity | Unit | **Columns/ Beams** | **Floors** | **Roofing** | **Foundations** | **Walls** |
|---|---|---|---|---|---|---|---|
| #15 Organic Felt | 99836.10 | m2 | | | 24959.025 | | |
| 1/2" Moisture Resistant Gypsum Board | 1169.39 | m2 | | | 1169.39 | | |
| 1/2" Regular Gypsum Board | 812.44 | m2 | | 812.44 | | | |
| 3 mil Polyethylene | 224.38 | m2 | | | | | 224.38 |
| Aluminum | 8.34 | Tonnes | | | | | 8.34 |
| Ballast (aggregate stone) | 6058570.25 | kg | | 5739523.25 | 319047 | | |
| Batt. Fiberglass | 449.55 | m2 (25mm) | | | | | 449.55 |
| Blown Cellulose | 11297.36 | m2 (25mm) | | | 11297.36 | | |
| Cedar Wood Shiplap Siding | 1850.52 | m2 | | | | | 1850.52 |
| Cedar Wood Tongue and Groove Siding | 69.03 | m2 | | | | | 69.03 |
| Commercial(26 ga.) Steel Cladding | 1488.49 | m2 | | | | | 1488.49 |
| Concrete 20 MPa (flyash av) | 3589.31 | m3 | | 1652.93 | | 1930.71 | 5.67 |
| Concrete 30 MPa (flyash av) | 168.97 | m3 | 163.32 | | | | 5.65 |
| Concrete Blocks | 68977.12 | Blocks | | | | | 68977.12 |
| EPDM membrane (black, 60 mil) | 722.53 | kg | | | | | 722.53 |
| Expanded Polystyrene | 361.65 | m2 (25mm) | | | 355.14 | | 6.51 |
| Foam Polyisocyanurate | 2355.79 | m2 (25mm) | | 2355.79 | | | |
| Galvanized Decking | 11.03 | Tonnes | | | 11.03 | 0.00 | |
| Galvanized Sheet | 203.74 | Tonnes | | | 202.31 | | 1.43 |
| Galvanized Studs | 7.11 | Tonnes | | | 6.54 | | 0.57 |
| Glazing Panel | 1.88 | Tonnes | | | | | 1.88 |
| GluLam Sections | 232.90 | m3 | 66.18 | 10.66 | 156.06 | | |
| Hollow Structural Steel | 3.00 | Tonnes | 3.00 | | | | |
| Joint Compound | 0.81 | Tonnes | | 0.81 | | | |
| Laminated Veneer Lumber | 17.62 | m3 | | 17.62 | | | |
| Large Dimension Softwood Lumber, kiln-dried | 83.12 | m3 | | | 83.12 | | |
| Modified Bitumen membrane | 332.9734 | kg | | | 332.9734 | | |
| Mortar | 1319.33 | m3 | | | | | 1319.33 |
| Nails | 3.41 | Tonnes | | 0.08 | 2.20 | | 1.13 |
| Open Web Joists | 5.97 | Tonnes | | | 5.97 | | |
| Oriented Strand Board | 40482.16 | m2 (9mm) | | | 40482.16 | | |
| Paper Tape | 0.01 | Tonnes | | 0.01 | | | |
| Parallel Strand Lumber | 4.89 | m3 | | 4.89 | | | |
| Pine Wood tongue and groove siding | 1915.19 | m2 | | 1915.19 | | | |
| Polyethylene Filter Fabric | 0.3602 | Tonnes | | | 0.3602 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rebar, Rod, Light Sections | 1141.82 | Tonnes | 77.28 | 823.68 | | 10.12 | 230.74 |
| Roofing Asphalt | 64472.7304 | kg | | | 64472.73 | | |
| Screws Nuts & Bolts | 0.38 | Tonnes | | | 0.12 | | 0.26 |
| Small Dimension Softwood Lumber, kiln-dried | 293.42 | m3 | | 17.72 | 243.13 | 2.63 | 29.95 |
| Softwood Plywood | 2473.37 | m2 (9mm) | | 480.71 | 687.56 | | 1305.09 |
| Solvent Based Alkyd Paint | 30.73 | L | | | 25.4258 | | 5.31 |
| Standard Glazing | 489.38 | m2 | | | | | 466.12 |
| Steel Tubing | 27.07 | Tonnes | 27.07 | | | | |
| Type III Glass Felt | 11193.2154 | m2 | | | 11193.215 | | |
| Water Based Latex Paint | 1513.62 | L | | | | | 1513.62 |
| Welded Wire Mesh / Ladder Wire | 9.38 | Tonnes | | | | 9.38 | |
| Wide Flange Sections | 18.83 | Tonnes | 18.83 | | | | |

## *4.2 Impact Assessment*

The data presented below in the following tables was collected from the output of the Impact Estimator. The earthworks data was determined using a Swedish report for estimating the impacts due to the excavation of site material. The summary measures reviewed were: fossil fuel consumption, weighted resource use, global warming potential, acidification potential, human health effects, eutrophication potential, ozone depletion potential, and smog potential as outlined in TRACI.

Fossil fuel consumption is the total amount of fossil fuel energy required to produce and construct the material and the weighted resource use is associated with the total mass of resources used in the construction and manufacturing stages. Global Warming Potential is a measure of the amount of carbon dioxide equivalent that is emitted from the manufacture and consumption of all the building materials in each assembly. This indicator is useful in comparing the assemblies for their contribution towards climate change, which is an evolving environmental issue.

The acidification potential is calculated by determining the equivalent amount of sulphur dioxide that is emitted in association with each assembly. This determines the potential for acid rain production, which is harmful to the environment. Human health effects are a calculated value based on the relative toxicity associated with the compounds emitted during the life cycle stages for the materials manufactured and constructed. The eutrophication potential is measured in mass of nitrogen and is associated with the potential of the materials to contribute to the environmental phenomenon of eutrophication, which is the enrichment of natural bodies of water with nutrients leading to anoxic effects. Ozone depletion is a measure of CFC-11 equivalent in the atmosphere that is emitted from the use of the assemblies and is associated with the breakdown of the ozone and the stratospheric layers in the ozone. Finally, smog formation is a measure of NOx equivalents, which results in the development of smog, especially in large urban centres.

The life cycle categories that these impacts were broken down into are related to the building material manufactured as well as the construction of the materials as outlined by the system boundary. Each impact and life cycle stage is broken up by respective building assembly so that assemblies can be compared.

**Table 2: Fuel Consumption Impact Assessment**

| Life Cycle Stage | | Fossil Fuel Consumption MJ | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 44,032,356 | 2,587,003 | 7,224,135 | 2,915,445 | 28,008,592 | 3,297,181 |
| | Transportation | 2,286,249 | 178,316 | 154,202 | 75,859 | 1,655,408 | 222,464 |
| Construction | Material | 374,913 | 323,165 | 0 | 251 | 13,484 | 38,013 |
| | Transportation | 5,340,075 | 323,355 | 251,397 | 89,113 | 4,390,943 | 285,267 |
| | Earthworks | - | | | | | |

**Table 3: Weighted Resource Use Impact Assessment**

| Life Cycle Stage | | Weighted Resource Use (kg) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 7.53E+07 | 4.86E+06 | 2.53E+06 | 1.10E+06 | 6.18E+07 | 5.01E+06 |
| | Transportation | 58,095.03 | 5,334.30 | 4,471.44 | 2,087.60 | 39,963.96 | 6,237.73 |
| Construction | Material | 8,694.34 | 7,490.48 | 0 | 6.16 | 316.23 | 881.47 |
| | Transportation | 125,738.22 | 7,616.18 | 5,921.46 | 2,084.88 | 103,394.58 | 6,721.11 |
| | Earthworks | - | | | | | |

## Table 4: Global Warming Potential Impact Assessment

| Life Cycle Stage | | Global Warming Potential (kg CO2 eq) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 2,972,720.10 | 392,956.80 | 663,948.91 | 180,667.01 | 1,350,003.06 | 385,144.33 |
| | Transportation | 172,403.04 | 13,385.93 | 12,179.27 | 5,765.19 | 124,389.48 | 16,683.17 |
| Construction | Material | 25,471.49 | 21,185.17 | 0 | 39.07 | 1,633.87 | 2,613.38 |
| | Transportation | 382,752.95 | 23,650.28 | 18,415.18 | 3,776.13 | 315,653.37 | 21,257.99 |
| | Earthworks | 1.28E+02 | | | | | |

## Table 5: Acidification Potential Impact Assessment

| Life Cycle Stage | | Acidification Potential (moles of H+ eq) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 1,168,783.45 | 156,294.09 | 296,084.24 | 63,715.55 | 492,221.29 | 160,468.28 |
| | Transportation | 58,406.28 | 5,452.00 | 4,717.53 | 2,066.17 | 39,836.93 | 6,333.65 |
| Construction | Material | 12,430.43 | 10,226.12 | 0 | 20.13 | 881.18 | 1,303.00 |
| | Transportation | 125,155.78 | 7,604.20 | 5,913.52 | 1,946.83 | 102,961.38 | 6,729.87 |
| | Earthworks | 219,717.19 | | | | | |

## Table 6: Human Health Impact Assessment

| Life Cycle Stage | | HH Respiratory Effects Potential (kg PM2.5 eq) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 97,346.99 | 1,141.65 | 1,952.46 | 361.35 | 92,733.41 | 1,158.13 |
| | Transportation | 70.40 | 6.62 | 5.71 | 2.50 | 47.91 | 7.67 |
| Construction | Material | 13.22 | 10.78 | 0 | 0.03 | 0.91 | 1.49 |
| | Transportation | 150.64 | 9.15 | 7.11 | 2.38 | 123.91 | 8.09 |
| | Earthworks | 1,064.53 | | | | | |

## Table 7: Eutrophication Potential Impact Assessment

| Life Cycle Stage | | Eutrophication Potential (kg N eq) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 2,371.84 | 115.10 | 448.91 | 188.95 | 1,479.87 | 139.01 |
| | Transportation | 60.78 | 5.73 | 4.95 | 2.16 | 41.31 | 6.64 |
| Construction | Material | 11.35 | 9.51 | 0 | 0.01 | 0.54 | 1.29 |
| | Transportation | 129.96 | 7.89 | 6.13 | 2.07 | 106.90 | 6.97 |
| | Earthworks | 0.16 | | | | | |

## Table 8: Ozone Depletion Potential Impact Assessment

| Life Cycle Stage | | Ozone Depletion Potential (kg CFC-11 eq) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 2.63E-03 | 7.50E-04 | 1.11E-03 | 9.39E-05 | 3.07E-05 | 6.46E-04 |
| | Transportation | 7.10E-06 | 5.60E-07 | 5.08E-07 | 2.39E-07 | 5.10E-06 | 6.94E-07 |
| Construction | Material | 5.29E-10 | 0 | 0 | 4.02E-11 | 4.41E-10 | 4.79E-11 |
| | Transportation | 1.57E-05 | 9.69E-07 | 7.55E-07 | 1.57E-07 | 1.29E-05 | 8.71E-07 |
| | Earthworks | 0 | | | | | |

**Table 9: Smog Potential Impact Assessment**

| Life Cycle Stage | | Smog Potential (kg NOx eq) | Foundations | Walls | Columns and Beams | Roofs | Floors |
|---|---|---|---|---|---|---|---|
| Manufacturing | Material | 10,891.34 | 2,020.15 | 3,028.03 | 525.22 | 3,277.62 | 2,040.32 |
| | Transportation | 1,316.01 | 125.41 | 108.06 | 46.88 | 891.05 | 144.61 |
| Construction | Material | 286.59 | 241.54 | 0 | 0.16 | 13.15 | 31.74 |
| | Transportation | 2,803.80 | 170.06 | 132.23 | 45.22 | 2,306.02 | 150.27 |
| | Earthworks | 2.10 | | | | | |

## *4.3 Uncertainty*

As discussed before, LCAs are complex and many assumptions are associated with the modeling stage. Therefore, uncertainty is a factor that must be discussed and understood when interpreting results. Major sources of uncertainty for this project stemmed from the assumptions made, the tools used (IE) and the data vintage. Due to the lack of data, results were based on engineering assumptions and IE also created uncertainty through its input limitations. For example, the mixed columns and beams had a limitation of 13.7 m on supported span length. However, the arenas typically had a supported span greater than 20 m. To accommodate IE, the inputs were tailored to the smallest bay size and supported span displayed in the drawings and correlated to the correct amount of columns. More uncertainty occurred from this input since the beams had to be modeled as extra basic materials - i.e. no beams were used in the mixed columns and beams input - given their complex geometry. Data vintage also contributed to the uncertainty because information was not available or legible, necessitating that further assumptions be made for the report.

Other considerations for uncertainty include the system boundary defined within the scope. The scope only encompasses the construction of the building and not the operational impacts. If used for comparative assertion, then the values may not be appropriate because the maintenance or operation of the building may significantly contribute to the impacts. The lack of maintenance cycles reported here may sway the reader to believe one venue is better than the other solely based on construction related values. Furthermore, since the 1968 Thunderbird

Arena is dated and construction methods may no longer be used, the findings may not be applicable for comparative assertions of current methodologies.

Unknown characterization factors, the region of study (also known as spatial variability) and time dependent (temporal) variability are also points of uncertainty. Spatial variability provides uncertainty because the study was done in a specific region and the results vary in different regions. For example, IEs assumptions on the electricity grid mix in Vancouver may vary from that of Arizona, therefore, the studies outcome is sensitive to the region chosen and the assumptions made on the fuel pricing. The temporal variability uncertainties are associated with time dependent impacts and how the impacts vary over time. Since this study did not incorporate time dependent impacts, such as climate change, construction practices and types of materials, inherent uncertainty is present.

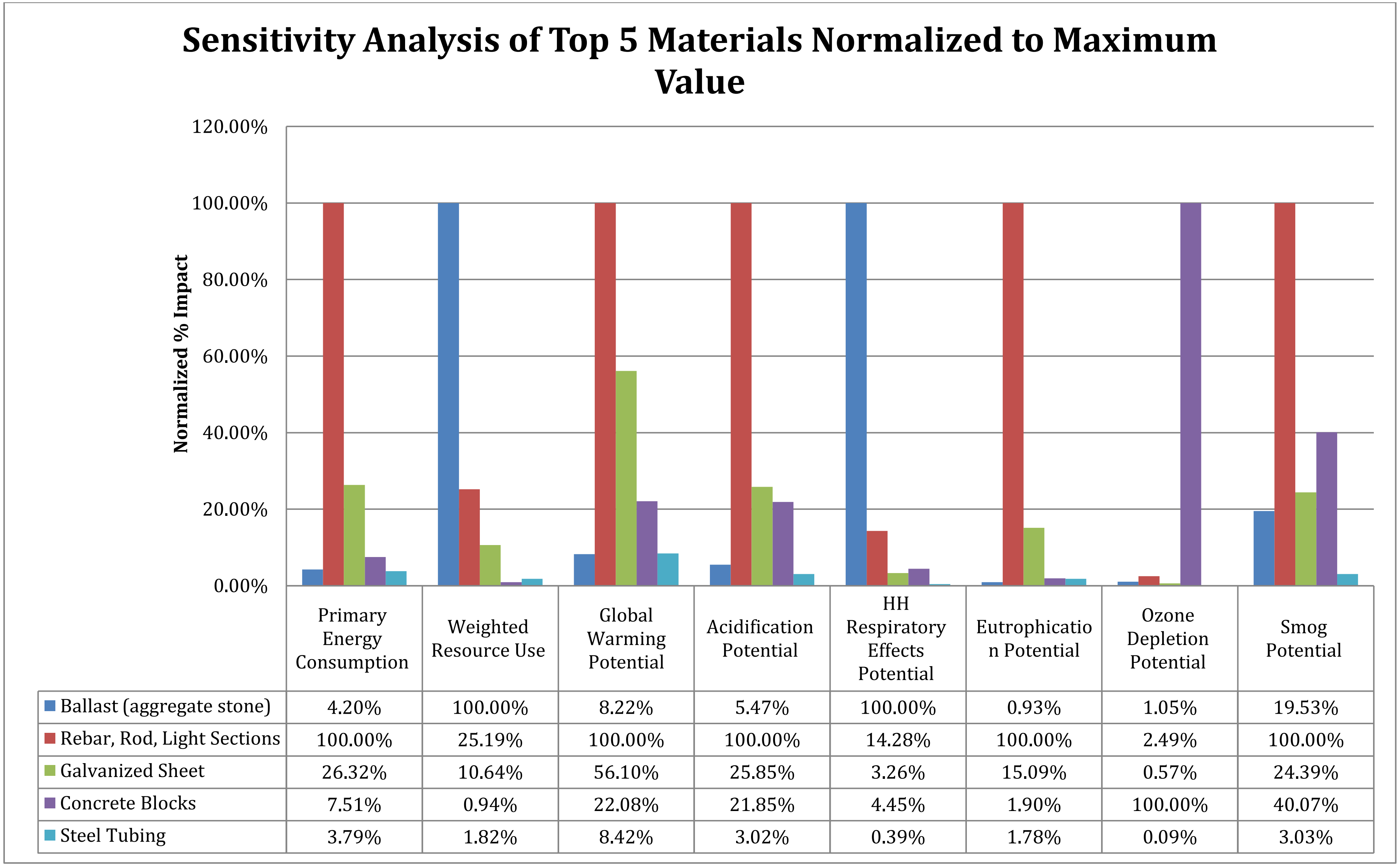
## *4.4 Sensitivity Analysis*

Conducting a sensitivity analysis is crucial to the interpretation and accuracy of the results obtained through IE. It is important to understand how the uncertainty in the derived building materials (On-Screen Takeoffs) relates to the generated impact data.

Sensitivity analysis was conducted for the top 5 materials by mass as listed in the bill of materials. Although mass was used for the basis of the analysis. It should be noted that the top 5 materials by mass do not guarantee that they create the largest environmental impact. Evaluating the top five materials by mass follows the logic of trucking capacity and therefore the material-related presence on site.

The materials identified in descending mass values are as follows: ballast (aggregate stone), rebar, galvanized sheet, concrete blocks, and steel tubing. Each material was increased by 10%, including the waste factor, and the results observed are displayed graphically below in the following figures.

The following diagram illustrates the impact of the identified materials normalized to the maximum impacts created by the materials identified. Each category of impact has one material that is normalized to 100% of the maximum change observed through a 10% change in mass of the material. It is evident that rebar is the most significant, setting the maximum percent impact increase for five out of eight categories.

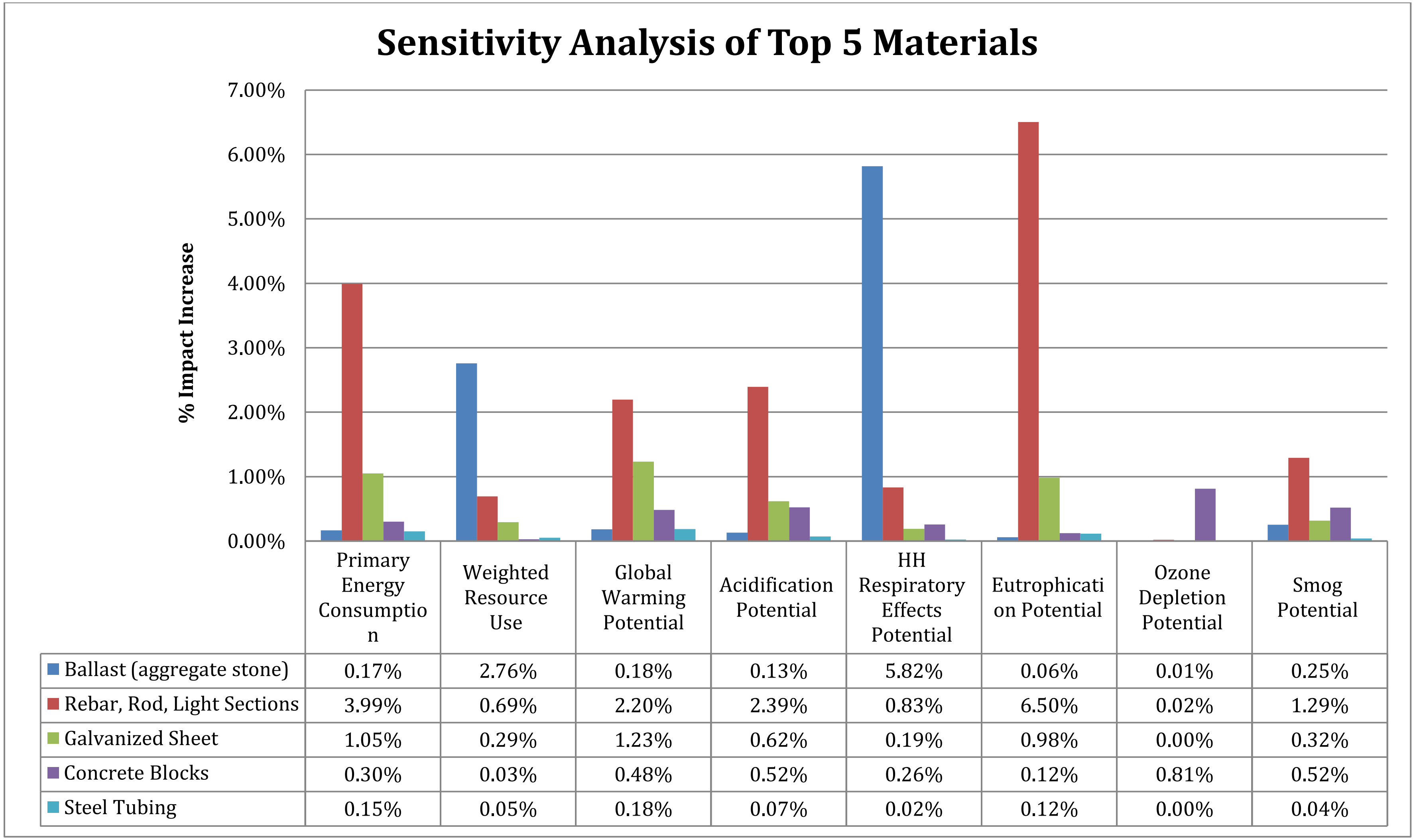


| | Primary Energy Consumption | Weighted Resource Use | Global Warming Potential | Acidification Potential | HH Respiratory Effects Potential | Eutrophication Potential | Ozone Depletion Potential | Smog Potential |
|---|---|---|---|---|---|---|---|---|
| Ballast (aggregate stone) | 4.20% | 100.00% | 8.22% | 5.47% | 100.00% | 0.93% | 1.05% | 19.53% |
| Rebar, Rod, Light Sections | 100.00% | 25.19% | 100.00% | 100.00% | 14.28% | 100.00% | 2.49% | 100.00% |
| Galvanized Sheet | 26.32% | 10.64% | 56.10% | 25.85% | 3.26% | 15.09% | 0.57% | 24.39% |
| Concrete Blocks | 7.51% | 0.94% | 22.08% | 21.85% | 4.45% | 1.90% | 100.00% | 40.07% |
| Steel Tubing | 3.79% | 1.82% | 8.42% | 3.02% | 0.39% | 1.78% | 0.09% | 3.03% |

**Figure 5: Sensitivity Analysis of Top 5 Materials Normalized to Maximum Value**

Similarly, the figure below illustrates the sensitivity of the % impact increase in the total impact as a result of 10% increase in weight. The figure below differs with the figure above in that it gives an idea of the total impact as opposed to the relative impact. For example, ozone depletion potential in the figure has a normalized value of 100%, however only a percent increase value of 0.81%, however, galvanized sheet with a normalized value of 56% has a total increase in value of 1.23%.

Sensitivity analysis is crucial during the building design/major renovation stage as it identifies each material's impact contribution to the total building and how those impacts may change with subtle changes in material quantities. A designer, for example, can use this information to identify materials suitable for substitution in the goal of reducing total impact. This information may be coupled with costs of materials in order to generate an optimum building impact cost analysis, which may aid key decisions in design and operations for future Olympic Venues. Although the sensitivity analysis for this report only included the top 5 materials, a complete sensitivity analysis is recommended in order to obtain complete information on which to base decisions.



| | Primary Energy Consumption | Weighted Resource Use | Global Warming Potential | Acidification Potential | HH Respiratory Effects Potential | Eutrophication Potential | Ozone Depletion Potential | Smog Potential |
|---|---|---|---|---|---|---|---|---|
| 🟦 Ballast (aggregate stone) | 0.17% | 2.76% | 0.18% | 0.13% | 5.82% | 0.06% | 0.01% | 0.25% |
| 🟥 Rebar, Rod, Light Sections | 3.99% | 0.69% | 2.20% | 2.39% | 0.83% | 6.50% | 0.02% | 1.29% |
| 🟩 Galvanized Sheet | 1.05% | 0.29% | 1.23% | 0.62% | 0.19% | 0.98% | 0.00% | 0.32% |
| 🟪 Concrete Blocks | 0.30% | 0.03% | 0.48% | 0.52% | 0.26% | 0.12% | 0.81% | 0.52% |
| 🟦 Steel Tubing | 0.15% | 0.05% | 0.18% | 0.07% | 0.02% | 0.12% | 0.00% | 0.04% |

**Figure 6: Sensitivity Analysis Top 5 Materials**

## *4.5 Functions and Impacts*

This section establishes the functions that the Thunderbird Arena (Old) served during its lifetime and presents the functional units by which the impacts of the building should be measured. The functional units are also presented to show the total building impacts per functional unit.

### 4.5.1 Building Functions

The building functions were discussed prior to starting the project and were outlined in the Goal and Scope section. Takeoffs were done to find the square footage of each of the functional areas and were used to find the percentage of the building's total area. The majority of the venue is comprised of multipurpose rinks at 52.7% of the total surface area. Hallways and concourses was the second largest category with 15.8% of the total surface area. The third largest category for the venue was the total seating at 10.1% of the building. The remaining building functions are relatively smaller in comparison to the rinks, hallways and seating and can be seen in the following table.

**Table 10: Building functions**

| **Room Type** | **Area (square meters)** | **Area (sq. ft)** | **Percentage of Total Building Area** |
|---|---:|---:|---:|
| Administrative Areas | 52.40 | 564 | 0.5% |
| Food Services | 234.02 | 2519 | 2.1% |
| Hallways/Concourses | 1798.05 | 19354 | 15.8% |
| Washrooms/Change Rooms | 830.74 | 8942 | 7.3% |
| Multipurpose Courts | 425.03 | 4575 | 3.7% |
| Multipurpose Rinks | 5987.89 | 64453 | 52.7% |
| Revenue Sources | 325.25 | 3501 | 2.9% |
| Storage | 215.91 | 2324 | 1.9% |
| Utilities | 349.59 | 3763 | 3.1% |
| Seating | 1145.40 | 12329 | 10.1% |
| **Total** | **11364.28** | **122324** | **100.0%** |

### 4.5.2 Functional Units

The functional unit in a LCA is used to express impacts relative to the performance of the system, or in this case, the performance of the building. As discussed, the building is used to provide entertainment to those watching the activities that take place inside them, and a location for competition to occur. The purpose of the LCA is to determine the effect that Olympic Venues have so that considerations can be made for future Olympics when choosing venue locations.

For the case of the Old Thunderbird Arena, only one of the buildings- Father Bauer Arena- still exists in the New Thunderbird Arena (post-renovation), which was used during the Olympics. Therefore, a majority of the building did not serve any function during the Olympics. Considering the purpose of the building and the functions that it serves the functional units can be broken down as follows:

- Per generic floor area
- Per function-specific floor area (as defined above)
- Per number of athletes that can compete at any given time in the facility
- Per number of spectators capable of viewing activities

The generic floor area is used to determine the impact that each constructed square foot has. The function of the building at the highest level is to provide shelter for various activities and therefore, this functional unit captures this impact. The various functional areas of the building are defined in the previous section. Based on these functions, the total building impact for each area can be defined to determine which functional area has the largest impact. The main function of the building is to provide a facility for athletes to compete or participate in various sports including hockey, curling, and squash/racquet ball. By calculating the number of athletes that can participate in sport at any given time will determine the total building impact per athlete. This functional unit is determined by dividing the total building impact by the number of athletes that can participate in hockey in the three arenas, curling in the curling rink, and squash/racquet ball in the court areas. The number of athletes for each sport will be determined based on the typical number of athletes on each sport-specific team (Table 13a). Finally, the functional unit per number of spectators capable of viewing activities will determine the total building impact based on the entertainment function of the building. This will be calculated by dividing the total building impact by the occupancy of the spectator areas (Table 14).

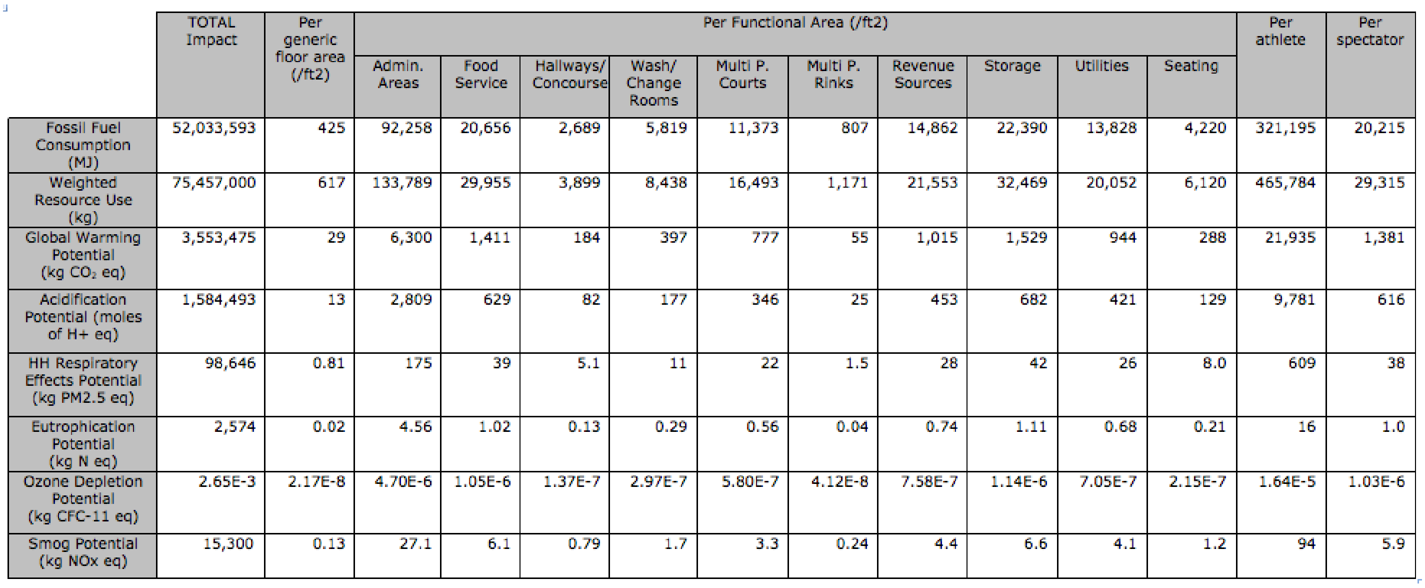
**Table 11: Number of Athletes (a) and Number of Spectators (b) per Activity Area**

| Area | # Athletes |
|---|---:|
| Dual Rink | 80 |
| Hockey Rink | 40 |
| Curling Rink | 30 |
| Handball/ Squash | 12 |
| Total | 162 |

| Area | # Spectators |
|---|---:|
| Dual Rink | 1,274 |
| Hockey Rink | 980 |
| Curling Rink | 200 |
| Handball/ Squash | 120 |
| Total | 2,574 |

The following table shows the calculated functional units for the Old Thunderbird Arena:

**Table 12: Functional Units**



|  | TOTAL Impact | Per generic floor area (/ft2) | Per Functional Area (/ft2) |  |  |  |  |  |  |  |  |  | Per athlete | Per spectator |
|---|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
|  |  |  | Admin. Areas | Food Service | Hallways/ Concourse | Wash/ Change Rooms | Multi P. Courts | Multi P. Rinks | Revenue Sources | Storage | Utilities | Seating |  |  |
| Fossil Fuel Consumption (MJ) | 52,033,593 | 425 | 92,258 | 20,656 | 2,689 | 5,819 | 11,373 | 807 | 14,862 | 22,390 | 13,828 | 4,220 | 321,195 | 20,215 |
| Weighted Resource Use (kg) | 75,457,000 | 617 | 133,789 | 29,955 | 3,899 | 8,438 | 16,493 | 1,171 | 21,553 | 32,469 | 20,052 | 6,120 | 465,784 | 29,315 |
| Global Warming Potential (kg $CO_2$ eq) | 3,553,475 | 29 | 6,300 | 1,411 | 184 | 397 | 777 | 55 | 1,015 | 1,529 | 944 | 288 | 21,935 | 1,381 |
| Acidification Potential (moles of H+ eq) | 1,584,493 | 13 | 2,809 | 629 | 82 | 177 | 346 | 25 | 453 | 682 | 421 | 129 | 9,781 | 616 |
| HH Respiratory Effects Potential (kg PM2.5 eq) | 98,646 | 0.81 | 175 | 39 | 5.1 | 11 | 22 | 1.5 | 28 | 42 | 26 | 8.0 | 609 | 38 |
| Eutrophication Potential (kg N eq) | 2,574 | 0.02 | 4.56 | 1.02 | 0.13 | 0.29 | 0.56 | 0.04 | 0.74 | 1.11 | 0.68 | 0.21 | 16 | 1.0 |
| Ozone Depletion Potential (kg CFC-11 eq) | 2.65E-3 | 2.17E-8 | 4.70E-6 | 1.05E-6 | 1.37E-7 | 2.97E-7 | 5.80E-7 | 4.12E-8 | 7.58E-7 | 1.14E-6 | 7.05E-7 | 2.15E-7 | 1.64E-5 | 1.03E-6 |
| Smog Potential (kg NOx eq) | 15,300 | 0.13 | 27.1 | 6.1 | 0.79 | 1.7 | 3.3 | 0.24 | 4.4 | 6.6 | 4.1 | 1.2 | 94 | 5.9 |

# 5.0 CONCLUSIONS

A Life Cycle Assessment (LCA) was used as a tool used to estimate the impacts a building has on the environment based on the construction. The intended application of the Old Thunderbird Arena LCA is to aid in future policy making, to improve LCA methods, add value to developing projects, and aid in the comparison of Olympic Venues. By completing LCAs for Olympic venues, better decisions can be made in the construction and selection of future venues for Olympics. This LCA will be useful for the interested general public, academics, relative industry, the IOC and future host cities.

This LCA evaluates the impacts related to the following construction assemblies for each of the life cycle stages including manufacturing, transportation, and construction:

- Earthworks
- Foundations
- Beams and Columns
- Walls
- Roofs
- Floors

From the study of the Old Thunderbird Arena it was found that the top five materials used during construction were aggregate rock, rebar, galvanized sheeting, steel tubing and concrete block. The summary measures indicated that the walls and roof assemblies resulted in the highest impacts. Sensitivity analysis indicated that rebar was the most sensitive to changes in the impact category.

Recommendations for future improvements on this report include accessing better data to help strengthen the model. Also, the limitations in the IE software should be corrected to allow for more accurate modeling and results. The results from this report should be used in conjunction with supported documentation when critically reviewing the impact of recreational complexes.

# APPENDICES

# *Appendix A – IE Input Document*

# *Appendix B – IE Assumptions Document*