UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Life Cycle Assessment of UBC Faculty of Pharmaceutical Sciences Building

Helia Amiri, Mahshid Hashemi

University of British Columbia

CIVL 498E

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PROVISIO

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

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

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

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CIVL 498E Final Report

Helia Amiri

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Abstract

The Life Cycle Assessment of the UBC Faculty of Pharmaceutical Sciences and Center for Drug Research and Development was performed in order to evaluate its environmental impacts. This building is currently under construction and in order to attain the most reliable data and to evaluate their performance and impacts on the environment, more accurate data collection is required. Which itself requires more accurate and up to date drawings and models. This project was done through modeling the building using On-Screen Takeoff and Athena Impact Estimator software. Since this building is under construction, BIM model was found helpful and more updated than structural and architectural drawings and was used as a supplement to these drawings.

According to the Bill of Materials obtained from On-Screen Takeoff and Athena Impact Estimator, five most significant materials of this building were recognized to be concrete 30Mpa, 5/8" Fire-Rated Type X Gypsum Board, glazing panels, galvanized studs and rebar rod, and light sections.

The output from the Impact Estimator (IE) is a list of impact category during the manufacturing and construction phases to the end-of-life stage of the building. The results of the study in terms of the impact categories are as follow:

- Global warming potential: 1.04E+07 *kg* CO_2 *eq*
- Ozone layer depletion: 1.51E-02 *kg CFC-11 eq*
- Acidification potential: 4.12E+06 *moles of* H^+ *eq*
- Eutrophication potential: 5.16E+03 *kg N eq*

- Smog potential: 4.99E+04 *kg NOx eq*
- Human health respiratory effects: 4.14E+04 *kg PM2.5 eq*
- Weighted resource use: 5.60E+07 *ecologically weighted kg*
- Fossil fuel use: 1.08E+08 *MJ*

After performing Sensitivity Analysis on the five most common materials in the building and evaluating their effects on each impact category, walls show great impacts on global warming, ozone layer depletion, acidification potential, smog potential, human health respiratory effects, and fossil fuel use more than other assemblies. Also, columns and beams have the major contribution to eutrophication potential impact category since they mainly consist of concrete and rebar. Floors play the main role in impact potential of weighted resource use.

Table of Contents

1 Introduction

UBC Faculty of Pharmaceutical sciences and center for drug research and development is located at the corner of Wesbrook Mall and Agronomy Road on the UBC Point Grey Campus. The Pharmaceutical building with a gross area of 22,871 square meter houses for the first time under one roof all the teaching, learning, research and community outreach activities of the Faculty of Pharmaceutical Sciences. The six storey building provides teaching and learning spaces including lecture halls and classrooms and seminar rooms, as well as study spaces for students. The building also includes a pharmacist clinic, three floors of research spaces, and a data center.

It is a 155 million dollar project with the Leadership in Energy and Environmental Design (LEED) Gold certificate. The project is started in mid 2010 and is intended to be finished in summer 2012.

The Pharmaceutical building is a reinforced concrete building with the major structural and envelope characteristics outlined in the table below:

Table 1 Building Characteristics of Pharmaceutical Building

Structure	Concrete columns supporting concrete suspended slab
Floors	Basement: Concrete SOG, Level -1 interstitial: Steel joist floor, Other levels: Concrete suspended slab
Exterior walls	Curtain wall
Interior walls	Concrete cast in place walls, gypsum on steel stud walls, Metal clad wall, Masonry partition wall, and Curtain wall
Window	All the exterior walls are curtain walls
Roof	Concrete suspended slab with two SBS sheet membrane, protection board and two layers of rigid insulation
Mechanical	Heat Exchange System

2 Goal & Scope

In accordance with the ISO 14040 and 14044 standards, this report will provide sections to describe the Goal and Scope. The following Goal and Scope section outlines the details of the LCA study that was carried out on the Pharmaceutical Building Project.

The Goal & Scope is critical to documenting the context and guiding an LCA study's execution. The purpose of defining the Goal of the study is to unambiguously state the context of the study, whereas the Scope details how the actual modeling of the study was carried out.

For this Pharmaceutical Building LCA study report, the format immediately below has been used to unambiguously outline the details of the parameters outlined in ISO 14040 and 14044.

Parameter Name

Parameter definition.

Details of how this item is defined for the Pharmaceutical Building LCA study.

This format has been followed throughout the Goal & Scope in order to provide the audience with an explanation each parameter and transparently state how it is defined for the Pahrmaceutical LCA study.

2.1 Goal of Study

The following are descriptions for a set of parameters which unambiguously state the context of the Pharmaceutical Building LCA study.

Intended application

Describes the purpose of the LCA study.

This LCA study will be used to evaluate the environmental impacts of the new building.

Reasons for carrying out the study

Describes the motivation for carrying out the study.

The report itself is an educational asset to help disseminate education on LCA and help further the development of this scientific method into sustainability in building construction practices at UBC and the green building industry as LCA is rapidly gaining acceptance at all scales of sustainable construction standards and corporate social responsibility policy.

Intended audience

Describes those who the LCA study is intended to be interpreted by.

The results of this study are to be primarily communicated to the public. In addition to the general public, the LCA report is intended to be communicated to industry and governments groups observing and involved in green building, as LCA is an emerging topic of significance in this area.The results would also be helpful for projects stake holders such as Construction Manager (Ledcor Construction), designers team (Stantec Consulting, Core Group Consultants, GHL Consultants, Morrison Hershfield) and the Architects (Saucier + Perrotte Architects, Hughes Condon Marler Architects)

Intended for comparative assertions

State whether the results of this LCA study are to be compared with the results of other LCA studies.

The results of this LCA study are not intended for comparative assertions. However; Its a benchmark so it can be used to drive to development performance based green design.

2.2 Scope of Study

The following are descriptions for a set of parameters that detail how the actual modeling of the study was carried out.

Product system to be studied

Describes the collection of unit processes that will be included in the study.

A unit process is a measurable activity that consumes inputs and emits outputs as a result of providing a product or service. The main processes that make up the product system to be studied in this LCA study are, the manufacturing of construction products (Figure 1), the construction of a building (Figure 2),maintenance which is a combination of demolition, manufacturing and construction itself, Operating Energy (Figure 3) and the demolition of it (Figure 4**Error! Reference source not found.**. These three processes are the building blocks of the LCA models that have been developed to describe the impacts associated with the Pharmaceutical Building. The unit processes and inputs and outputs considered within these three main processes are outlined below.

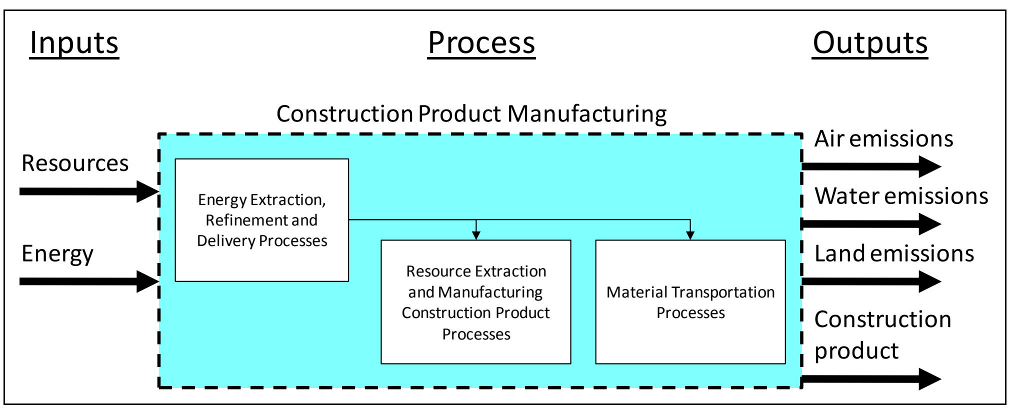

Figure 1- Generic unit processes considered within Construction Product Manufacturing process by Impact Estimator software.

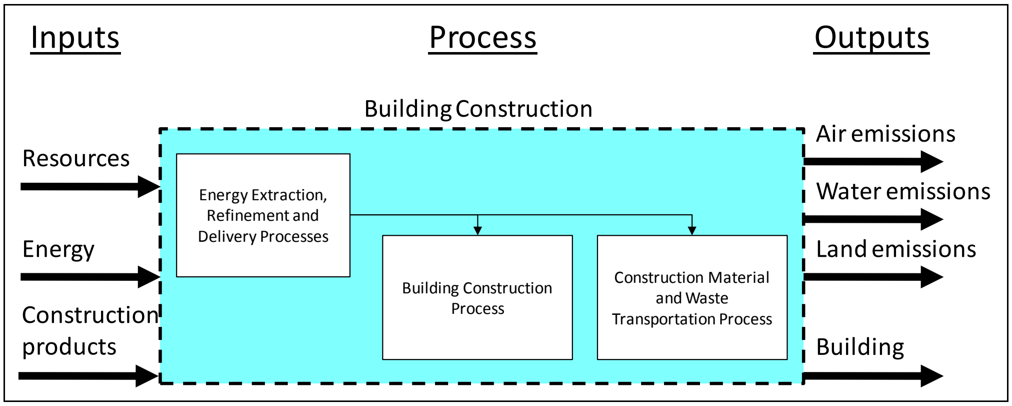

Figure 2- Generic unit processes considered within Building Construction process by Impact Estimator software.

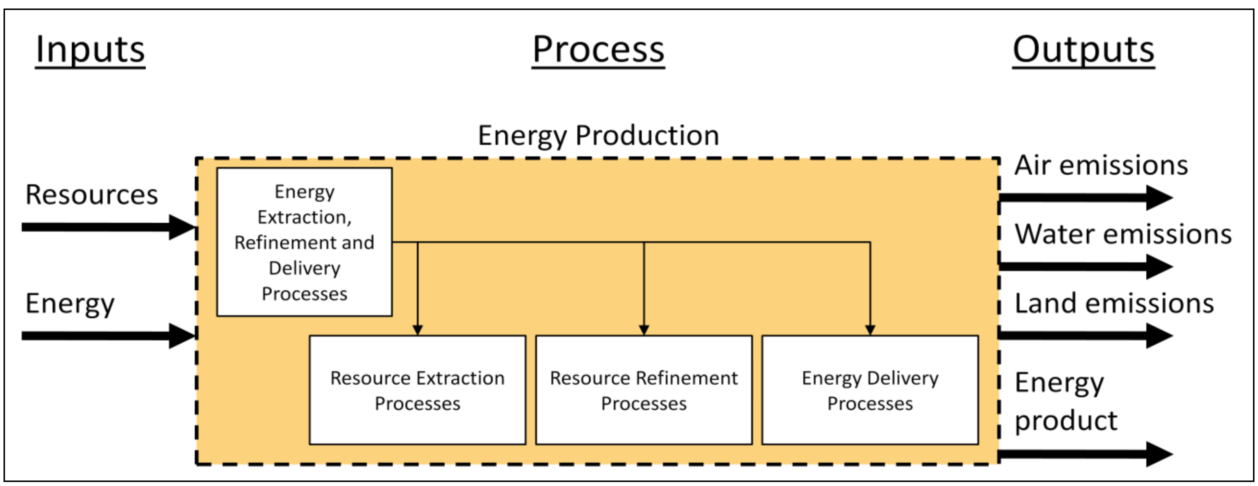

Figure 3- Generic unit processes considered within Energy Production process by Impact Estimator software.

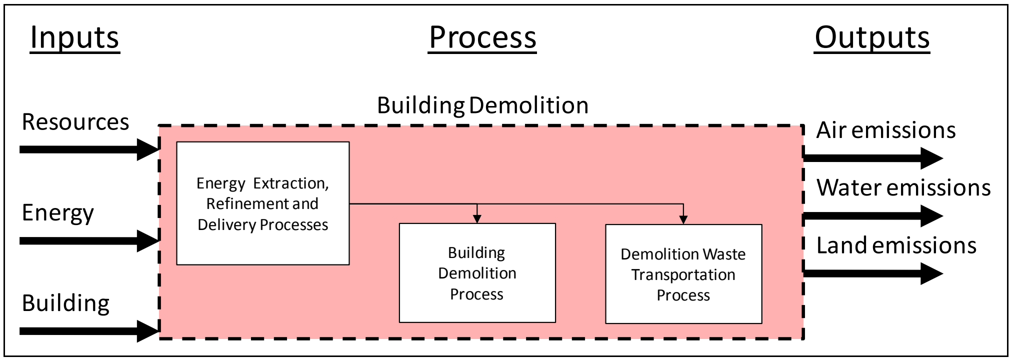

Figure 4- Generic unit processes considered within Building Demolition process by Impact Estimator software.

As seen in the above figures, the inputs and outputs occurring at the various stages in a buildings life cycle are captured. The construction product manufacturing, building construction processes, energy production processes, building maintenance process, and the building demolition unit process capture the capture the cradle to grave process. The organization of these processes into the product systems to describe the environmental impacts of the new building requires the definition of a system boundary. Thus, the product system studied in this Pharmaceutical Building LCA study is further defined in the system boundary section below.

System boundary

Details the extent of the product system to be studied in terms of product components, life cycle stages, and unit processes.

This study includes the construction products used to create their structures and envelopes. This indicates that product components must be defined the materials within the products studied.

The material product components (i.e. building assemblies) that were included from the products (i.e. buildings) are the footings, slabs on grade, walls, columns and beams, roofs, as well as all associated doors and windows, gypsum board, vapour barriers, insulation, cladding, roofing, and curtain walls. These material product components are in turn assemblies of construction products.

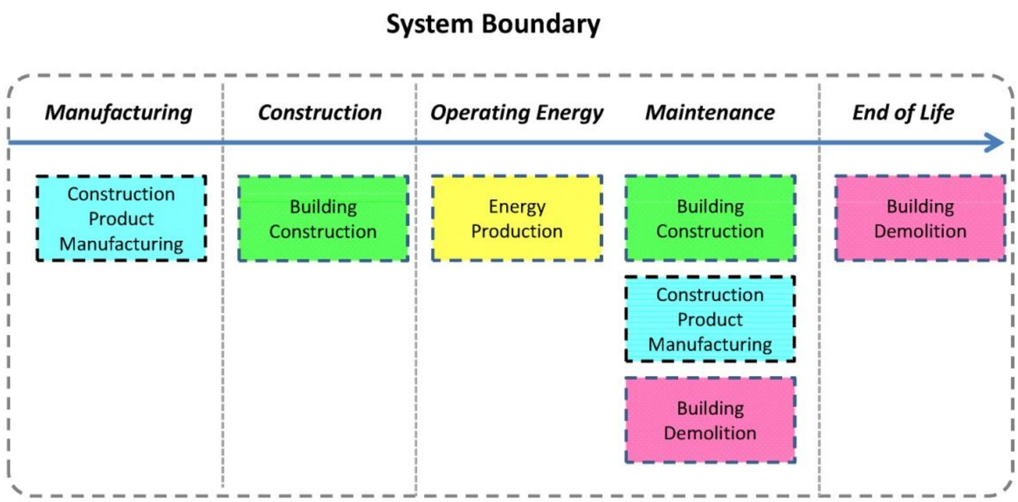

Figure 5- System boundary for Renovation and Building New scenarios.

The life cycle stages considered in the Pharmaceutical Building include those spanning from cradle-to-grave. The Process begins from site preparation, starting with resource extraction and manufacturing of construction products, the building construction process then it goes to the maintenance and operating energy phase and it ends with building demolition process. shows the system boundary defined for this project.

Functions of the product system

Describes the functions served by the product focused on in the LCA study.

A description of the Pharmaceutical building's major functions hase been outlined in the Introduction of this report.

Functional unit

A performance characteristic of the product system being studied that will be used as a reference unit to normalize the results of the study.

The functional units used in this study to normalize the LCA results for the Pharmaceutical Buildings include:

- *per generic post-secondary academic building square meter constructed*
- *per specific post-secondary academic building square meter constructed*
- *per generic post-secondary academic building cubic meter constructed*
- *Per Dollar spent on the investment*

Further discussion of these functional units and their application are contained in the Impact Assessment sub-section under Functions and Impacts.

Allocation procedures

Describes how the input and output flows of the studied product system (and unit processes within it) are distributed between it and other related product systems.

The problem of allocation arises in three situations – i) when a process produces more than one product, ii) a waste treatment process collectively treats multiple wastes products and iii) when materials are recycled or reused in subsequent life cycles. An allocation problem arises in these situations because the input and output flows from the processes must be shared amongst the products and subsequent life cycles.

In this study, the cut-off allocation method was used, which entails that only the impacts directly caused by a product within a given life cycle stage are allocated to that product. The LCA starts from extracting the raw material and doesn't include the process that the raw material is created and ends with the demolition phase and doesn't include the treatment of the demolished materials.

Impact assessment methodology and categories selected

State the methodology used to characterize the LCI results and the impact categories that will address the environmental and other issues of concern.

The primary impact assessment method used in the Pharmaceutical Building LCA study was the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), developed by the US Environmental Protection Agency (US EPA). The impact assessment methodology developed by the Athena Institute was also used to characterize weighted raw resource use and fossil fuel consumption.

The impact categories selected and the units used to express them (i.e. category indicators) are listed below.

- Global warming potential – kg CO_2 equivalents
- Acidification potential – H^+ mol equivalents
- Eutrophication potential – kg N equivalents
- Ozone depletion potential – kg CFC^{-11} equivalents
- Photochemical smog potential – kg NOx equivalents
- Human health respiratory effects potential – kg $PM_{2.5}$ equivalents
- Weighted raw resource use – kg
- Fossil fuel consumption – MJ

Short descriptions of each of these impact categories are provided in the Impact Assessment sub-section in Results and Interpretation.

Interpretation to be used

Statement of significant issues, model evaluation results and concluding remarks.

Analysis and discussions of uncertainty, sensitivity, and functional units of this LCA study are contained in the Results and Interpretation section of this report, whereas concluding remarks are contained in the Conclusion.

Assumptions

Explicit statement of all assumptions used to by the modeler to measure, calculate or estimate information in order to complete the study of the product system.

As with data sources, there were two main areas where assumptions were integrated, which include – performing materials takeoffs of building assemblies and those contained within the Impact Estimator.

The details of the methods used in completing the material take offs on the building drawings are summarized in the Model Development section of this report.

All of the inputs and assumptions associated with interfacing these takeoffs with the Impact Estimator are documented in the Input Document (**Error! Reference source not found.**) and the Assumptions Document (**Error! Reference source not found.**). Assumptions were typically required in the development of building assembly information due to missing information as well as limitations in construction product LCI data and assembly characteristics in the Impact Estimator.

Assumptions regarding the completion of take offs to estimate material use, referenced LCI data and transportation networks have all been developed by the Athena Institute and are built into the Impact Estimator version 4.1.14 12 This information is proprietary; however, parts can be accessed through the inner workings report found on the Athena Institute webpage.[1]

Value choices and optional elements

Details the application and use of normalization, grouping, weighting and further data quality analysis used to better understand the LCA study results.

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[1] –V4.1 Software and Database Overview

http://www.athenasmi.org/wp-content/uploads/2011/10/ImpactEstimatorSoftwareAndDatabaseOverview.pdf

Value choices and optional elements were not included in this study due to limited time and resources; however, this report does provide sufficient documentation for its audience to carry out these types of analyses.

Limitations

Describe the extents to which the results of the modeling carried out on the product system accurately estimate the impacts created by the product system defined by the system boundary of the study.

The following limitations should be considered when interpreting the results of this LCA study:

System Boundary – Any of the impacts created or avoided through the reuse, recycling or waste treatment of the construction or demolition wastes emitted were outside the scope of this study.

Data Sources and Assumptions – This LCA study used original architectural and structural drawings obtained to develop information on the building assemblies in the partial construction of the Pharmaceutical Building. The resulting LCA models are specific to this building as their bills of materials reflect its unique design. Furthermore, the life cycle inventory flows and their characterization reflect averages of industry processes and their impacts for North America. This is due to the fact that those industries engaged in the North American construction market are currently not providing this LCI data. Furthermore, it was not possible to regionalize the impacts of processes and their inventory flows due to time and resource constraints in conducting this study.

Data quality requirements

Qualitative and quantitative description of the sourced data used in the study including its age, geographical and technological coverage, precision, completeness, reproducibility and uncertainty.

The sources of data used in the development of this LCA study include those used to estimate results for the bill of materials, life cycle inventory (LCI) flows and the characterization of LCI flows.

Bill of materials - Architectural and structural drawings were obtained to develop information on the building assemblies. Building Information Modeling (BIM) also contributed information were information was either missing or unclear in the drawings. The precision of the quantity take offs does rely somewhat on the quantity takeoffs built into the Impact Estimator, as the quantity take offs from the drawings are input and completed by the Impact Estimator. However, the use of the Impact Estimator does enable these results to be reproduced due to all results being documented in the Inputs and Assumptions Documents contained in Appendix A and B in this report.

LCI flows – The Athena LCI Database was the source of LCI data. The quality of the data and modeling assumptions used to develop the Athena LCI Database (which is built into the Impact Estimator) was outside the time and resource constraints of this study. However, some of this information can be accessed through the Athena Institute webpage's Software database overview and the LCI Databases [2], [3]. Generally speaking, this database is specific to the current

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[2] http://www.athenasmi.org/our-software-data/lca-databases/

North American context, and thus does create some geographic and temporal limitations on this study. For instance, i) The construction product manufacturing as well as fuel refining and production LCI data is based on North American averages ii) The transportation matrix that estimates distances and modes for construction product transportation as well as construction and demolition wastes is specific to Vancouver, British Columbia iii) The LCI data and modeling parameters in the Impact Estimator were developed by the Athena Institute to reflect current circumstances and technologies.

Characterization factors – Documentation of the US EPA TRACI impact assessment method can be found on the US EPA website[4], and documentation for the development of the weighted resource use impact category can be found on the Athena Institute webpage[5]. Generally speaking, this method characterized LCI flows to reflect their potential to cause damage on average in North America. Qualitative discussion of the uncertainties present in the impact assessment results are contained in this report in the Impact Assessment sub-section of Results and Interpretation.

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[3] The Inner Working of the Impact Estimator for Buildings: Transparency Document - http://www.athenasmi.org/tools/impactEstimator/innerWorkings.html

[4] US EPA TRACI documentation - http://www.epa.gov/nrmrl/std/traci/traci.html

[5] Weighted resource use impact category development - http://www.athenasmi.org/wp-content/uploads/2011/10/16_ECC_Impacts_of_Resource_Extraction.pdf

Type of critical review

A review of the methods, data, interpretations, transparency, and consistency of the LCA study.

A critical review has not been carried out in the study; however, every effort has been made to be transparent about how the LCA study was developed.

Type and format of the report required for the study

Statement of the type and format followed by the report.

This report followed the final report outline provided by Rob Sianchuk - the instructor of the LCA course this project was carried out under in the UBC Civil Engineering department.

3 Model development

3.1 Structure and Envelope

3.1.1 Material Takeoff Development

The material takeoffs have been done by using software called On-Screen Takeoff. This software can do quantity takeoffs from 2D drawings with a great accuracy. The structural and architectural drawings were used as the main source of information for quantity takeoffs; however, in case of lack of information, 3D models were used in conjunction to the drawings.

There are three types of conditions in On-Screen Takeoff: Linear Condition, Count Condition and Area Condition. Linear condition is for lineal elements such as walls, strip footings. To measure surface areas such as floor, opening sizes are measured via area condition. For counting objects such as footings or windows, count condition is being used.

All assembly types are organized in different layers in order to have easier access to data for different levels. For instance, having same type of partition wall on different level, the partition wall is measured in different levels as different conditions. In this case, one can understand how long of this partition wall is available in different levels. As a result, comparing different options for IE would be easier.

Incomplete information was one of the challenges that arose during the quantity takeoff. In order to overcome this issue, 3-D model was used as the first step to find more detailed and accurate information. If the issue was not solved using the 3-D model, the next step that was taken was talking to the site personnel and finally making an assumption if no information was found. All the assumptions, however, have been fully explained in Appendix B.

3.1.2 Material Takeoff Assumptions

Foundation

Foundation system of the building consists of concrete slab on grade (SOG) and concrete footings. Different types of footings such as spread footings, strip footings, and retaining wall foundations were used in this project. The footings can be found in the structural drawings. For the entire project, the concrete percentage of flyash is set to average in the Impact Estimator as no information was available on the drawings and 3-D models. The thickness of SOG is 150mm; however, due to IE limitations, it is modeled as a 200mm SOG and the required adjustments were made to the length and width in order to have equal amount of concrete.

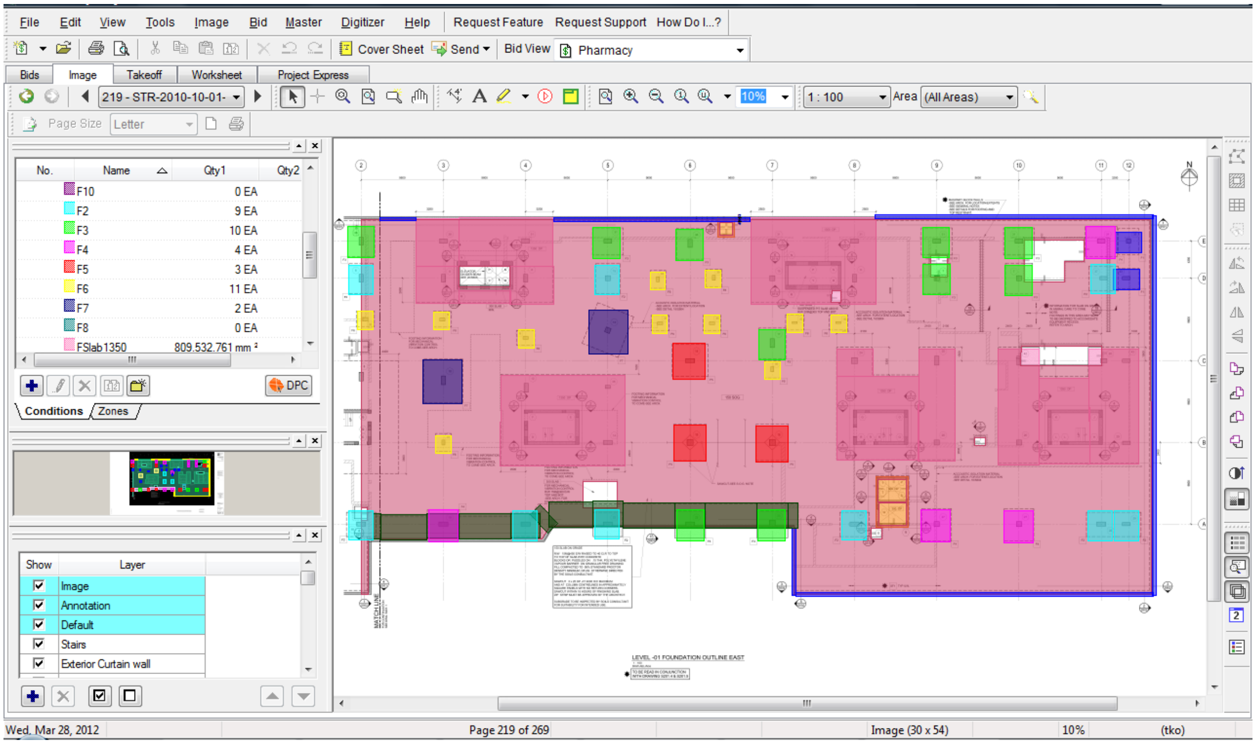

Figure 6 Quantity take off for foundation system

As IE has a limitation of 500 mm thickness for the footings, the thickness of those footings that was more than 500mm was set to 500 mm and the area is changed to have the same volume of concrete. Moreover, as IE has certain concrete strengths and rebar sizes, the actual values of strength and rebar size of footings have been rounded accordingly in order to compensate reinforced concrete strength.

The cross sections of stepped footings were measured using area condition and assuming the constant concrete volume and thickness limitations. They were modeled as rectangular footings. Concrete stairs were modeled as footings using area condition with an average of stair thickness.

Walls

This building consists of several wall types including cast in place, metal clad wall, masonry partition wall, and steel stud and curtain walls. Linear takeoffs were performed on the architectural drawings. As the height of each level varies, walls were categorized into different groups based on their level.

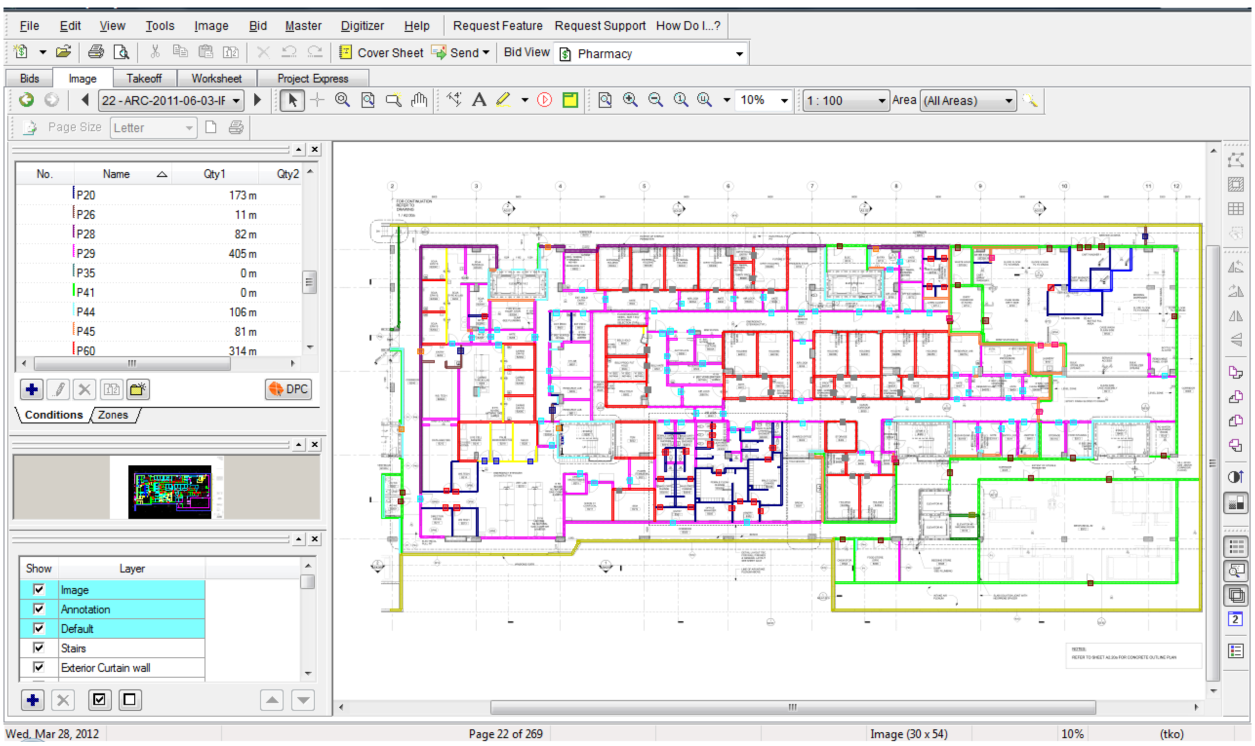

Figure 7 A sample of Quantity take off for wall assemblies

Due to thickness restriction of 200mm and 300mm in the IE, all of the walls required length adjustments to accommodate this limitation. Their length was reduced by a factor while keeping the volume constant and thickness at 200mm or 300mm. Some other assumption has been made, such as considering Polystyrene Extruded as the closest surrogate for Waterproof Membrane. Research shows that Dens Glass Gold Sheathing is essentially a fiberglass covered gypsum board that is also reinforced with glass fibers. This combination provides a product that is dimensionally stable, resistant to fire. This material is not an option in the IE, so it was not counted towards our results from IE. This is the same case for Zinc walls.

Moreover, some materials such as Galvanized Steel Z Bar are not an option under Wall Assembly in IE; thus, they have been categorized under Extra Basic Material as Galvanized Sheet.

According to the architectural drawings, masonry partition walls have unknown rebar size and it has been assumed to have the minimum rebar of #10. Also, based on the observation of drawings, all interior doors are assumed to be Hollow Core Wood interior door.

Columns and Beams

Count conditions were used on structural drawings to determine the number of columns and beams on each floor. The inputs to the IE are number of columns, number of beams, bay size, supported span, floor to floor height, and live load. The size of columns and beams are calculated automatically by IE based on these inputs.

Some assumptions have been made in order to accommodate the bay size limitation of range 3.05m to 12.20m in the IE. Also, based on structural drawings, some levels have varying live load. As the IE accepts one input for each level, the live load that covers most of the floor area is assumed to be the live load of the entire floor and neglect the live load that covers less area compare to the other one.

Floors

Takeoffs were performed on the structural drawings using area condition. Some adjustments have been made to the floor width in order to accommodate the span size range of 0.0m to 9.75m in the IE. Also, the IE calculates the floor thickness based on concrete strength, floor width, span, live load and flyash content. Floor width was calculated from the area divided by the span and the concrete flyash content was assumed to be average for the entire floor measurements. The maximum acceptable live load in the IE is 4.8kPa. On some levels the actual value of live load exceeds this limit; thus, it was assumed to be 4.8kPa.

All the levels have concrete suspended slab floor but level -01 interstitial, which has steel joist floor. In the IE, the acceptable span range for steel joist is between 0.0m to 5.5m. As a result, some adjustments have been made to the width by considering the area constant and the span size to the maximum of 5.5m to maintain within the acceptable range.

Roof

The shape of the plan is not a simple rectangle; thus, its width is calculated by using the area obtained from the takeoff and dividing it by the span. The span is assumed to be 40m. The average concrete flyash is assumed and concrete strength is set to be 30mpa.

Research showed that SBS Self-Adhering Base/Ply Sheet is a durable, modified bitumen membrane designed and manufactured to meet industry and code requirements; therefore, in the IE the material is set to Standard Modified Bitumen Membrane 2 ply which is assumed to be the closest surrogate. Also the thickness was adjusted to the minimum acceptable value in the IE. The minimum acceptable live load in the IE is 2.4kPa; thus, the roof live load was assumed to be 2.4kPa. More assumptions have been made for the roof and can be found in details in Appendix B.

Extra Basic Materials

Some materials were not available as an option in the IE; as a result, they were added to the IE under Extra Basic Materials. Example of such these assemblies is W41 that is covered with a layer of zinc. With considering the volume and density of the zinc, its weight was calculated and inputted into IE.

4 Results and interpretation

4.1 Inventory Analysis

4.1.1 Bill of Materials

Inputting all the required information in the IE, it gave a bill of material for all the components that was modeled in the software (Table 2). However, it is believed that comparing these materials in terms of quantities is not a sound comparison because of the different units. Concrete 30 MPa is one of the materials that is being used in the building in large amounts. This is mainly because all of the structural components are made of concrete especially from concrete 30Mpa. The same reasoning can be applied to Rebar, rod and light section material as rebar is used for reinforcing the concrete. In addition, both concrete and rebar have just three different choices in IE; therefore, to model them one should round up or down to one of the options in IE which makes the BOM over or under estimated. As almost all the Building envelope is curtain panel system, this material is one of the most used materials in the building; however, for the entire building envelope just one type of curtain panel system is assumed. In addition, an assumption was made for the percent viewable glazing and percent spandrel panel which can lead to over estimation of the material.

5/8" Fire-Rated Type X Gypsum Board is another material that is used a lot. Most of the interior walls have this kind of material in their assemblies. Furthermore, IE has limited types of gypsum board and in some cases this kind of Gypsum board was the closest choice to what is used in the building.

Another material that is used in large amounts was galvanized stud. This material is mainly used in walls because several types of interior walls were steel stud walls and because of the limited number of steel stud types, rounding was usually done. The steel joist floor in level -1 interstitial had galvanized stud as well.

Table 2 Bill of Materials for the pharmaceutical Building

Connstruction Material	***Units***	***Building Assembly***					***Building Total***
		Foundation	***Wall***	***Floors***	***Columns & Beams***	***Roof***	
5/8" Fire-Rated Type X Gypsum Board	m2	-	51,738.89	-	-	-	51,738.89
5/8" Gypsum Fibre Gypsum Board	m2	-	495.84	-	-	-	495.84
5/8" Moisture Resistant Gypsum Board	m2	-	3,477.91	-	-	-	3,477.91
6 mil Polyethylene	m2	-	-	-	-	4,173.22	4,173.22
Air Barrier	m2	-	3,536.09	-	-	-	3,536.09
Aluminum	Tonnes	-	108.95	-	-	-	108.95
Batt. Fiberglass	m2 (25mm)	-	86,385.89	-	-	-	86,385.89
Cedar Wood Bevel Siding	m2	-	1,921.24	-	-	-	1,921.24
Cold Rolled Sheet	Tonnes	-	1.66	-	-	-	1.66
Commercial(26 ga.) Steel Cladding	m2	-	6,465.94	-	-	-	6,465.94
Concrete 20 MPa (flyash av)	m3	288.02	-	39.62	-	-	327.64
Concrete 30 MPa (flyash av)	m3	3,287.25	2,114.58	8,052.02	3,137.34	1,393.53	17,984.72
Concrete Blocks	Blocks	-	22,850.01	-	-	-	22,850.01
EPDM membrane (black, 60 mil)	kg	-	6,828.27	-	-	-	6,828.27
Extruded Polystyrene	m2 (25mm)	-	8,471.59	-	-	4,091.38	12,562.97
Foam Polyisocyanurate	m2 (25mm)	-	-	-	-	16,486.95	16,486.95
Galvanized Sheet	Tonnes	-	21.91	-	-	-	21.91
Galvanized Studs	Tonnes	-	107.14	40.99	-	-	148.13
Glazing Panel	Tonnes	-	842.22	-	-	-	842.22
Hot Rolled Sheet	Tonnes	-	1.25	-	-	-	1.25
Joint Compound	Tonnes	-	55.60	-	-	-	55.60
Modified Bitumen membrane	kg	-	-	-	-	125,461.99	125,461.99
Mortar	m3	-	436.08	-	-	-	436.08
Nails	Tonnes	-	2.93	-	-	0.73	3.66

Connstruction Material	Units	Building Assembly					Building Total
		Foundation	Wall	Floors	Columns & Beams	Roof	
Paper Tape	Tonnes	-	0.64	-	-	-	0.64
Rebar, Rod, Light Sections	Tonnes	9.76	117.47	474.14	1,069.75	73.19	1,744.32
Screws Nuts & Bolts	Tonnes	-	7.99	0.59	11.41	-	19.99
Small Dimension Softwood Lumber, kiln-dried	m3	-	5.00	-	-	-	5.00
Softwood Plywood	m2 (9mm)	-	2,259.86	-	-	-	2,259.86
Solvent Based Alkyd Paint	L	-	25.17	-	-	-	25.17
Water Based Latex Paint	L	-	4,691.87	-	-	-	4,691.87
Welded Wire Mesh / Ladder Wire	Tonnes	6.22	-	-	-	-	6.22
Wide Flange Sections	Tonnes	-	-	-	217.13	-	217.13

4.2 Impact Assessment

The output from impact estimator is a list of impact category identified by US EPA. In this part for each impact category a description is provided using TRACI[6]. Then the results from the impact estimator are provided for each building assembly in different stages of the building and for the whole building as well. As LCA is a cradle to grave assessment, the results for each impact category are shown from manufacturing to end-of-life stage. These impact categories which are based on a midpoint approach are as follow:

4.2.1 Global Warming

Global warming which is categorized as pollution categories refers to the potential increase in the earth's temperature because of green house gases that trap heat

[6] The tool for the reduction and assessment of chemical and other environmental impacts

from reflected sunlight. This is a midpoint metric for calculation of the potency of greenhouse gases relative to CO2. Global Warming can lead to Malaria, coastal area damage, agricultural effects, forest damage, plant and animal effects. It is one of the biggest environmental issues that are being dealt with. Table 3 shows the global warming potential assessment of the building.

Table 3 Pharmaceutical Building Global warming potential Assessment

Life Cycle Stage	***Process***	***Global Warming Potential***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	kg CO2 eq	9.77E+05	2.44E+06	2.56E+06	1.62E+06	5.63E+05	8.16E+06
	Transportation	kg CO2 eq	2.90E+04	4.75E+04	7.44E+04	4.79E+04	1.28E+04	2.12E+05
	Total	kg CO2 eq	1.01E+06	2.49E+06	2.64E+06	1.67E+06	5.76E+05	8.38E+06
Construction	Material	kg CO2 eq	2.62E+04	3.93E+04	1.10E+05	2.51E+01	1.96E+04	1.96E+05
	Transportation	kg CO2 eq	4.35E+04	8.21E+04	1.01E+05	4.83E+04	2.25E+04	2.98E+05
	Total	kg CO2 eq	6.97E+04	1.21E+05	2.12E+05	4.83E+04	4.22E+04	4.93E+05
Maintenance	Material	kg CO2 eq	0.00E+00	1.07E+06	0.00E+00	0.00E+00	7.61E+04	1.14E+06
	Transportation	kg CO2 eq	0.00E+00	6.43E+04	0.00E+00	0.00E+00	2.40E+03	6.67E+04
	Total	kg CO2 eq	0.00E+00	1.13E+06	0.00E+00	0.00E+00	7.85E+04	1.21E+06
End-of-Life	Material	kg CO2 eq	2.56E+04	2.25E+04	6.20E+04	3.50E+04	1.05E+04	1.56E+05
	Transportation	kg CO2 eq	2.15E+04	2.28E+04	5.00E+04	2.20E+04	8.93E+03	1.25E+05
	Total	kg CO2 eq	4.71E+04	4.53E+04	1.12E+05	5.70E+04	1.94E+04	2.81E+05
Total Life Cycle			1.12E+06	3.79E+06	2.96E+06	1.77E+06	7.16E+05	1.04E+07

Based on the results, walls increase the potential for global warming more than other assemblies. Figure 8 shows the percentage of each assembly's contribution to the global warming.

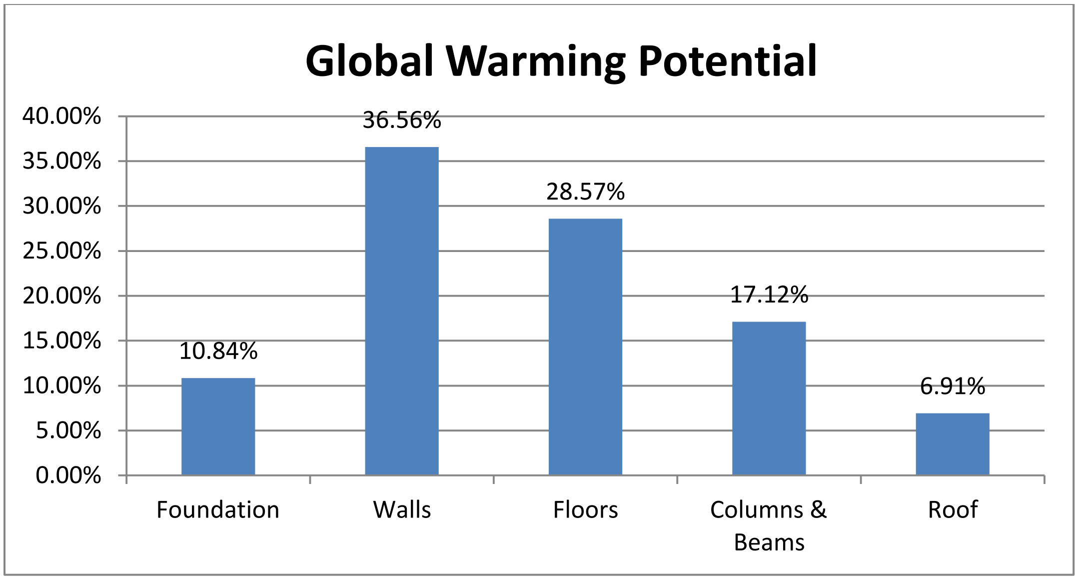

Figure 8. Percentage of each assembly's contribution to Global Warming Potential

4.2.2 Ozone Layer Depletion

Ozone layer depletion is the reduction of the Ozone protective layer which is caused by emissions of substances such as chlorofluorocarbons CFCs) and halons. Reduction in Ozone layer will increase UVB radiation which can cause Skin cancer, cataracts, material damage, immune system suppression, crop damage, other plant and animal effects. This category is measured in terms of mass equivalence of CFC-11. Table 4 shows the Ozone layer depletion assessment of the building.

Table 4 Pharmaceutical Ozone Layer Depletion Assessment

Life Cycle Stage	***Process***	***Ozone Layer Depletion***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	kg CFC-11 eq	1.98E-03	4.68E-03	4.58E-03	1.78E-03	8.08E-04	1.38E-02
	Transportation	kg CFC-11 eq	1.22E-06	2.00E-06	3.12E-06	1.99E-06	5.39E-07	8.87E-06
	Total	kg CFC-11 eq	1.98E-03	4.68E-03	4.59E-03	1.78E-03	8.09E-04	1.38E-02
Construction	Material	kg CFC-11 eq	0.00E+00	1.73E-09	0.00E+00	1.14E-11	0.00E+00	1.74E-09
	Transportation	kg CFC-11 eq	1.78E-06	3.37E-06	4.15E-06	1.99E-06	9.23E-07	1.22E-05
	Total	kg CFC-11 eq	1.78E-06	3.37E-06	4.15E-06	1.99E-06	9.23E-07	1.22E-05
Maintenance	Material	kg CFC-11 eq	0.00E+00	1.28E-03	0.00E+00	0.00E+00	5.07E-07	1.28E-03
	Transportation	kg CFC-11 eq	0.00E+00	2.64E-06	0.00E+00	0.00E+00	9.83E-08	2.74E-06
	Total	kg CFC-11 eq	0.00E+00	1.28E-03	0.00E+00	0.00E+00	6.05E-07	1.28E-03
End-of-Life	Material	kg CFC-11 eq	1.15E-06	1.01E-06	2.79E-06	1.58E-06	4.72E-07	7.01E-06
	Transportation	kg CFC-11 eq	8.81E-07	9.35E-07	2.05E-06	9.02E-07	3.66E-07	5.13E-06
	Total	kg CFC-11 eq	2.03E-06	1.95E-06	4.84E-06	2.48E-06	8.38E-07	1.21E-05
Total Life Cycle			1.98E-03	5.96E-03	4.60E-03	1.79E-03	8.11E-04	1.51E-02

Based on the results, Walls increase the potential for Ozone layer depletion more than other assemblies. Figure 9 shows the percentage of each assembly’s contribution to the Ozone layer depletion.

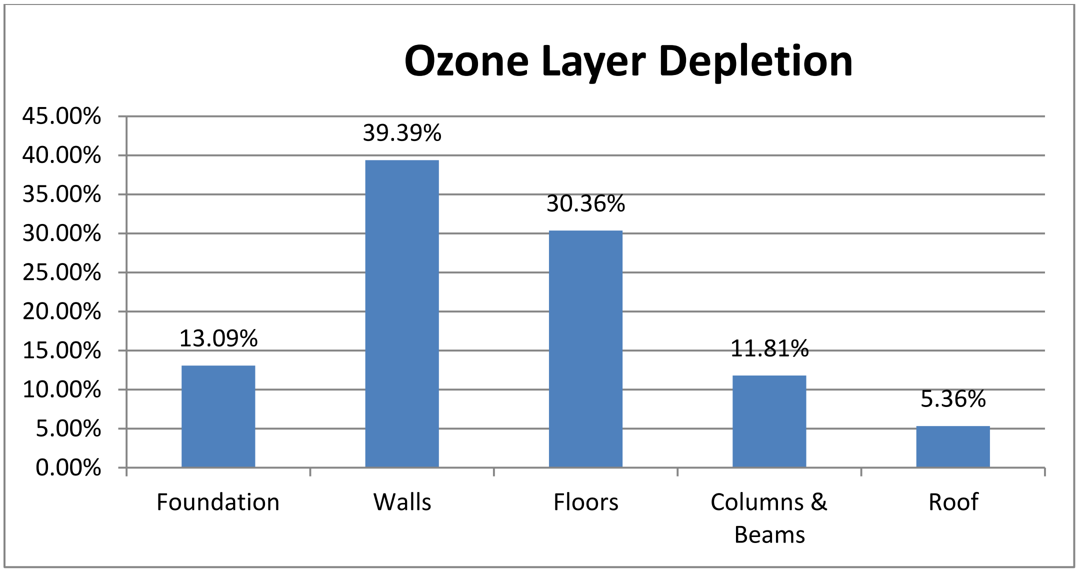

Figure 9 Percentage of each assembly's contribution to Ozone Layer Depletion

4.2.3 Acidification Potential

Acidification occurs when an increase in acidity of water and soil system occurs. Acid deposition has corrosive effect on buildings monuments and historical artifacts. It also can have effects on Plant, animal, and ecosystem effects Acidification is usually occurs due to high amount of SO_2 and NO_X. This category is usually expressed in H_ mole equivalent deposition per kilogram of emission. Table 5 shows the Acidification Potential assessment of the building.

Table 5 Pharmaceutical Building Acidification Potential Assessment

Life Cycle Stage	***Process***	***Acidification Potential***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	moles of H+ eq	3.34E+05	1.24E+06	8.68E+05	5.58E+05	1.83E+05	3.18E+06
	Transportation	moles of H+ eq	1.23E+04	2.04E+04	3.09E+04	1.82E+04	5.34E+03	8.71E+04
	Total	moles of H+ eq	3.46E+05	1.26E+06	8.99E+05	5.76E+05	1.88E+05	3.27E+06
Construction	Material	moles of H+ eq	1.36E+04	2.05E+04	5.00E+04	1.36E+01	8.86E+03	9.29E+04
	Transportation	moles of H+ eq	1.38E+04	2.85E+04	3.26E+04	1.86E+04	7.12E+03	1.01E+05
	Total	moles of H+ eq	2.74E+04	4.90E+04	8.26E+04	1.86E+04	1.60E+04	1.94E+05
Maintenance	Material	moles of H+ eq	0.00E+00	5.47E+05	0.00E+00	0.00E+00	4.45E+04	5.91E+05
	Transportation	moles of H+ eq	0.00E+00	2.13E+04	0.00E+00	0.00E+00	7.72E+02	2.21E+04
	Total	moles of H+ eq	0.00E+00	5.68E+05	0.00E+00	0.00E+00	4.53E+04	6.13E+05
End-of-Life	Material	moles of H+ eq	1.42E+03	1.25E+03	3.44E+03	1.94E+03	5.81E+02	8.62E+03
	Transportation	moles of H+ eq	6.78E+03	7.20E+03	1.58E+04	6.95E+03	2.82E+03	3.95E+04
	Total	moles of H+ eq	8.20E+03	8.45E+03	1.92E+04	8.89E+03	3.40E+03	4.81E+04
Total Life Cycle			3.82E+05	1.89E+06	1.00E+06	6.03E+05	2.53E+05	4.12E+06

Same as the previous impact categories, walls have the most significant effect on Acidification Potential. Figure 10 shows the percentage of each assembly's contribution to this impact category.

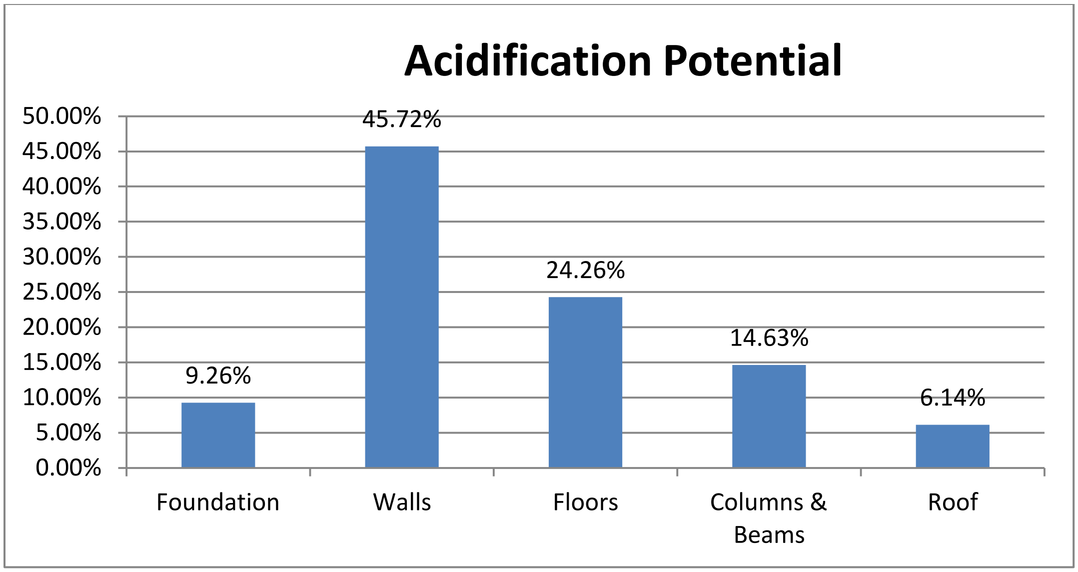

Figure 10 Percentage of each assembly's contribution to Acidification Potential

4.2.4 Eutrophication Potential

When water receives excessive nutrients, it leads to dense growth of plant life. The decomposition of plants depletes the supply of oxygen which leads to foul odor or taste, death or poisoning of fish[7] and human health impact. This impact category is characterized by equivalent mass of nitrogen basis. Table 6 shows the eutrophication potential assessment of the building.

Table 6. Pharmaceutical Building Eutrophication Potential Assessment

Life Cycle Stage	*Process*	*Eutrophication Potential*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
Manufacturing	Material	kg N eq	244.78	806.61	1,204.20	1,956.53	201.17	4,413.30
	Transportation	kg N eq	12.97	21.50	32.57	19.02	5.62	91.67
	Total	kg N eq	257.76	828.11	1,236.77	1,975.55	206.79	4,504.97
Construction	Material	kg N eq	11.82	19.15	50.06	0.01	8.88	89.91

[7] http://wordnetweb.princeton.edu/perl/webwn?s=eutrophication

Life Cycle Stage	*Process*	*Eutrophication Potential*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
	Transportation	kg N eq	14.32	29.75	33.82	19.49	7.38	104.75
	Total	kg N eq	26.14	48.89	83.88	19.50	16.25	194.66
Maintenance	Material	kg N eq	0.00	374.84	0.00	0.00	16.45	391.29
	Transportation	kg N eq	0.00	22.17	0.00	0.00	0.80	22.98
	Total	kg N eq	0.00	397.02	0.00	0.00	17.25	414.26
End-of-Life	Material	kg N eq	0.97	0.86	2.36	1.33	0.40	5.92
	Transportation	kg N eq	6.41	6.80	14.89	6.56	2.66	37.33
	Total	kg N eq	7.38	7.66	17.25	7.90	3.06	43.25
Total Life Cycle			2.91E+02	1.28E+03	1.34E+03	2.00E+03	2.43E+02	5.16E+03

Columns and beams have the major contribution to this impact category. Columns and beams majorly consist of concrete and rebar looking at BOM it can be seen that the amount of rebar in this building assembly is more than other assemblies. Therefore, they high effect of walls on eutrophication potential might be due to high amount of rebar being used in this assembly. Figure 11 shows the percentage of each assembly's contribution to this impact category.

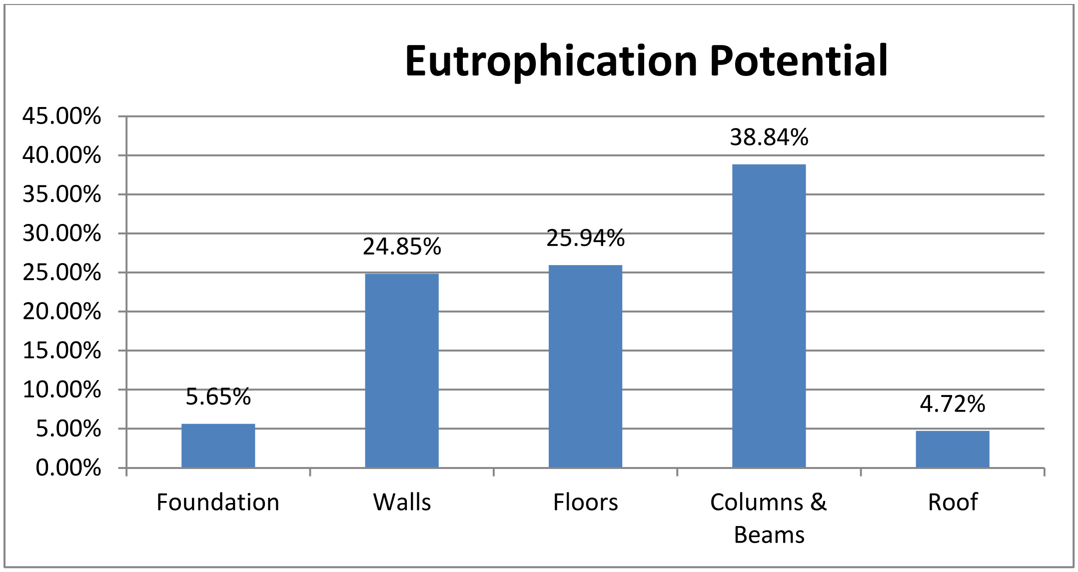

Figure 11 Percentage of each assembly's contribution to Eutrophication Potential

4.2.5 Smog Potential

Smog is a kind of pollution majorly resulting from vehicular emissions and industrial fumes. These emissions can react with the sunlight and form photochemical smog as well. Smog can lead to Human mortality, asthma effects, and plant effects. Smog potential will basically express as NO_X Equivalent. Table 7 shows the smog potential assessment of the building.

Table 7 Pharmaceutical Building Smog Potential Assessment

Life Cycle Stage	***Process***	***Smog Potential***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	kg NOx eq	4,940.72	10,025.87	11,920.34	5,697.83	2,679.78	35,264.54
	Transportation	kg NOx eq	284.45	471.50	713.33	414.44	122.97	2,006.68
	Total	kg NOx eq	5,225.16	10,497.37	12,633.67	6,112.27	2,802.75	37,271.22
Construction	Material	kg NOx eq	310.41	475.89	1,248.35	0.14	221.42	2,256.21
	Transportation	kg NOx eq	308.62	643.10	729.17	422.76	158.94	2,262.59
	Total	kg NOx eq	619.03	1,118.99	1,977.52	422.91	380.36	4,518.81
Maintenance	Material	kg NOx eq	0.00	5,882.20	0.00	0.00	747.69	6,629.89
	Transportation	kg NOx eq	0.00	478.98	0.00	0.00	17.28	496.26
	Total	kg NOx eq	0.00	6,361.18	0.00	0.00	764.97	7,126.15
End-of-Life	Material	kg NOx eq	18.22	16.04	44.16	24.94	7.47	110.82

Life Cycle Stage	*Process*	*Smog Potential*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
	Transportation	kg NOx eq	151.35	160.74	351.80	155.07	62.85	881.82
	Total	kg NOx eq	169.57	176.78	395.96	180.01	70.32	992.63
Total Life Cycle			6.01E+03	1.82E+04	1.50E+04	6.72E+03	4.02E+03	4.99E+04

Same as the other impact categories, walls have the most effective impact in smog potential. Figure 5 shows the percentage of each assembly's contribution to this impact category.

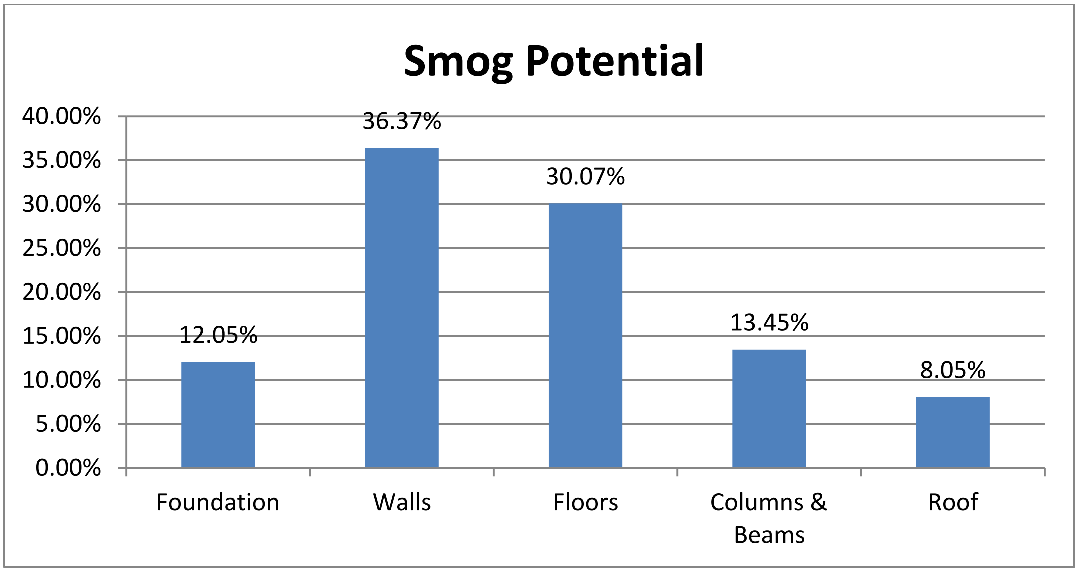

Figure 12 Percentage of each assembly's contribution to Smog Potential

4.2.6 Human Health Respiratory Effects

Human Health Respiratory Effects mainly focuses on the effect of particular matters (PM) on human's respiratory system health. This impact category is expressed through equivalent particular matter size ($PM_{2.5}$) Basis. Table 8 shows the Human Health Respiratory Effects assessment of the building.

Table 8. Pharmaceutical Building Human Health Respiratory Effects Assessment

Life Cycle Stage	*Process*	*Human Health Respiratory Effects*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
Manufacturing	Material	kg PM2.5 eq	2,275.93	14,618.78	5,629.69	3,108.77	1,080.44	26,713.61
	Transportation	kg PM2.5 eq	14.96	24.78	37.57	21.97	6.48	105.76
	Total	kg PM2.5 eq	2,290.89	14,643.56	5,667.26	3,130.75	1,086.91	26,819.37
Construction	Material	kg PM2.5 eq	13.39	22.85	56.72	0.01	10.06	103.04
	Transportation	kg PM2.5 eq	16.61	34.43	39.21	22.51	8.56	121.33
	Total	kg PM2.5 eq	30.00	57.28	95.94	22.53	18.61	224.36
Maintenance	Material	kg PM2.5 eq	0.00	14,133.01	0.00	0.00	167.85	14,300.86
	Transportation	kg PM2.5 eq	0.00	25.69	0.00	0.00	0.93	26.62
	Total	kg PM2.5 eq	0.00	14,158.71	0.00	0.00	168.78	14,327.49
End-of-Life	Material	kg PM2.5 eq	1.35	1.19	3.27	1.85	0.55	8.21
	Transportation	kg PM2.5 eq	8.15	8.66	18.94	8.35	3.38	47.48
	Total	kg PM2.5 eq	9.50	9.84	22.21	10.20	3.94	55.69
Total Life Cycle			2.33E+03	2.89E+04	5.79E+03	3.16E+03	1.28E+03	4.14E+04

Walls still have the most significant effect on this impact. Figure 13 shows the percentage of each assembly's contribution to this impact category.

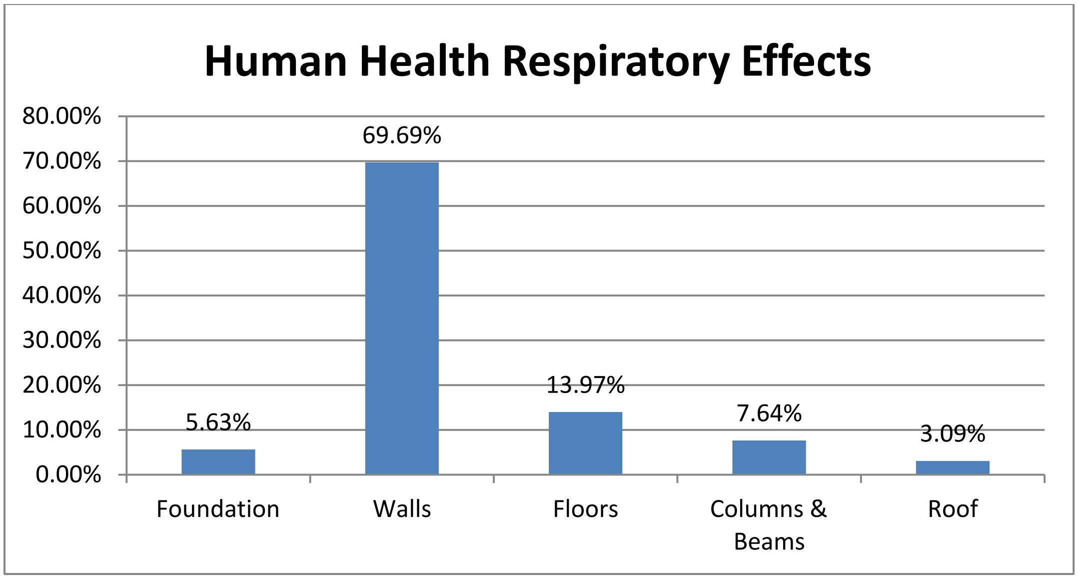

Figure 13 Percentage of each assembly's contribution to Human Health Respiratory Effects

4.2.7 Weighted Resource Use

Weighted Resource Use relates to the resources that used to manufacture building materials. It is reported as Kg. Table 9 shows the Weighted Resource Use assessment of the building.

Table 9 Pharmaceutical Building Weighted Resource Use Assessment

Life Cycle Stage	*Process*	*Weighted Resource Use*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
Manufacturing	Material	ecologically weighted kg	9.39E+06	8.86E+06	2.20E+07	1.00E+07	3.84E+06	5.42E+07
	Transportation	ecologically weighted kg	1.20E+04	2.14E+04	3.02E+04	1.78E+04	5.20E+03	8.65E+04
	Total	ecologically weighted kg	9.41E+06	8.88E+06	2.21E+07	1.01E+07	3.84E+06	5.42E+07
Construction	Material	ecologically weighted kg	8.99E+03	1.23E+04	3.78E+04	1.74E+00	6.72E+03	6.58E+04
	Transportation	ecologically weighted kg	1.38E+04	2.90E+04	3.27E+04	1.92E+04	7.11E+03	1.02E+05

Life Cycle Stage	Process	Weighted Resource Use	Assembly Group					Building Total
			Foundation	Walls	Floors	Columns & Beams	Roof	
	Total	ecologically weighted kg	2.28E+04	4.13E+04	7.05E+04	1.92E+04	1.38E+04	1.68E+05
Maintenance	Material	ecologically weighted kg	0.00E+00	1.35E+06	0.00E+00	0.00E+00	1.16E+05	1.47E+06
	Transportation	ecologically weighted kg	0.00E+00	2.13E+04	0.00E+00	0.00E+00	7.74E+02	2.21E+04
	Total	ecologically weighted kg	0.00E+00	1.37E+06	0.00E+00	0.00E+00	1.17E+05	1.49E+06
End-of-Life	Material	ecologically weighted kg	9.24E+03	8.13E+03	2.24E+04	1.26E+04	3.79E+03	5.62E+04
	Transportation	ecologically weighted kg	6.77E+03	7.19E+03	1.57E+04	6.93E+03	2.81E+03	3.94E+04
	Total	ecologically weighted kg	1.60E+04	1.53E+04	3.81E+04	1.96E+04	6.60E+03	9.56E+04
Total Life Cycle			9.45E+06	1.03E+07	2.22E+07	1.01E+07	3.98E+06	5.60E+07

Floors have the most impact on this impact category and play the main role. Figure 14 shows the percentage of each assembly's contribution to this impact category.

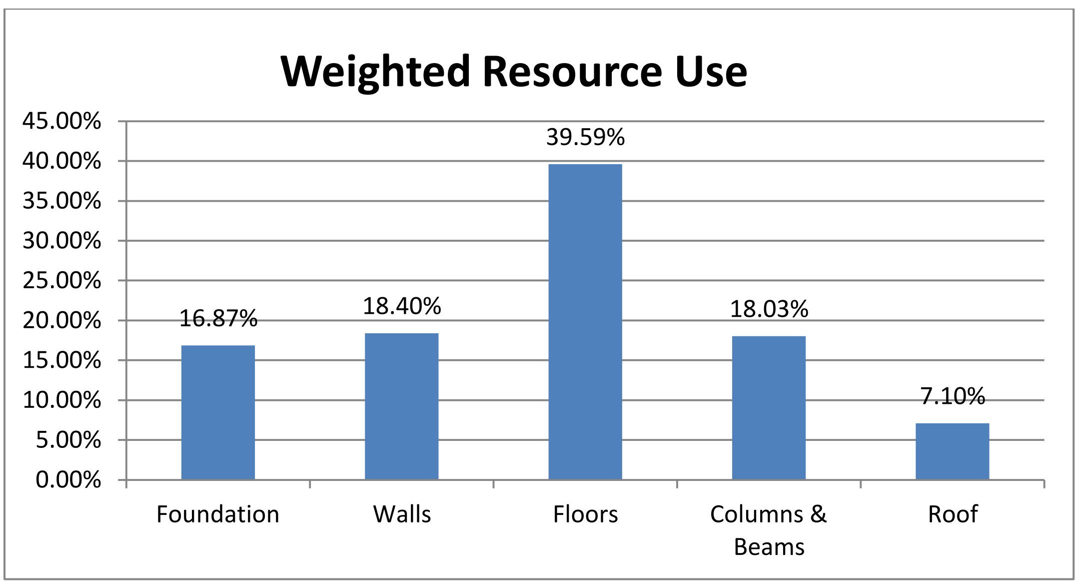

Figure 14 Percentage of each assembly's contribution to Weighted Resource Use

4.2.8 Fossil Fuel Use

Fossil fuel use is related to the energy use for manufacturing, transportation, construction and demolition of the materials during the life cycle of the building. It is shown as Mega Joules (MJ). Its shortage might lead to use of other sources of energy which may cause different environmental impacts. Table 10 shows the Fossil Fuel Use assessment of the building.

Table 10 Pharmaceutical Building Fossil Fuel Use Assessment

Life Cycle Stage	***Process***	***Fossil Fuel Use***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	MJ	5,984,184.11	23,374,055.46	21,406,743.65	25,722,870.53	6,253,977.74	82,741,831.48
	Transportation	MJ	511,130.76	913,766.29	1,286,736.34	758,090.58	221,684.03	3,691,408.00
	Total	MJ	6,495,314.87	24,287,821.74	22,693,479.98	26,480,961.11	6,475,661.77	86,433,239.48
Construction	Material	MJ	387,907.80	530,775.92	1,630,551.95	71.10	289,937.83	2,839,244.60
	Transportation	MJ	586,085.38	1,231,960.92	1,386,509.39	816,911.93	301,662.11	4,323,129.73
	Total	MJ	973,993.18	1,762,736.84	3,017,061.34	816,983.03	591,599.94	7,162,374.33
Maintenance	Material	MJ	0.00	4,825,336.59	0.00	0.00	4,405,228.92	9,230,565.51
	Transportation	MJ	0.00	905,944.29	0.00	0.00	32,856.06	938,800.35
	Total	MJ	0.00	5,731,280.88	0.00	0.00	4,438,084.98	10,169,365.86
End-of-Life	Material	MJ	392,245.60	345,318.66	950,758.04	536,983.54	160,808.26	2,386,114.09
	Transportation	MJ	287,220.82	305,040.50	667,616.13	294,283.63	119,267.89	1,673,428.96
	Total	MJ	679,466.41	650,359.16	1,618,374.17	831,267.16	280,076.15	4,059,543.05
Total Life Cycle			8.15E+06	3.24E+07	2.73E+07	2.81E+07	1.18E+07	1.08E+08

From the table above, it can be seen that like other impact categories walls, columns and beams, and floors cause almost the same proportion of fossil fuel use. Figure 15 shows the percentage of each assembly's contribution to this impact category.

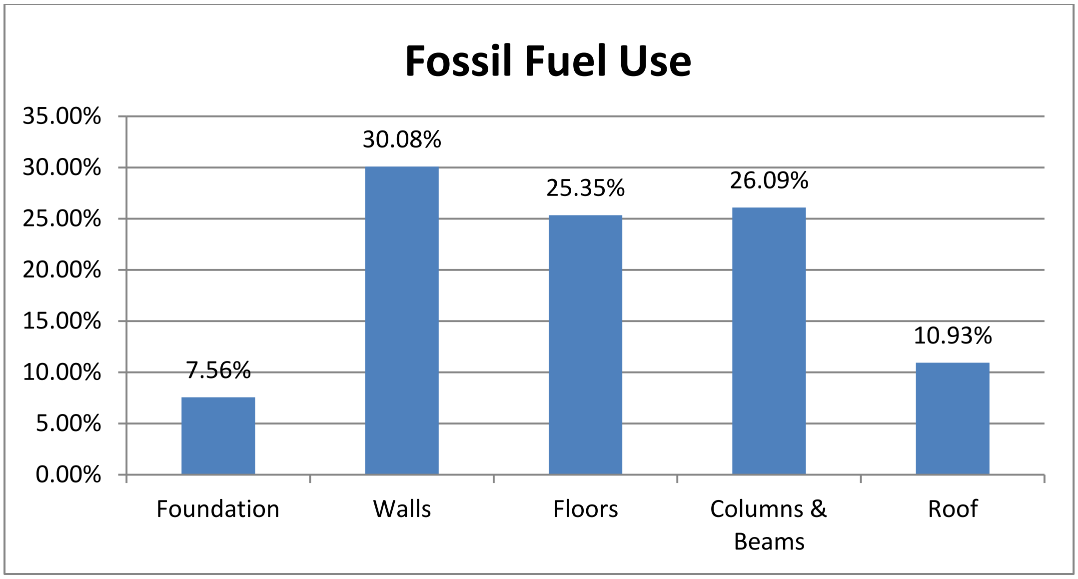

Figure 15 Percentage of each assembly's contribution to Fossil fuel use

4.3 Uncertainty

Considering LCA as a decision tool, it is important to know to which extent the outcomes are reliable. As LCA involves data gatherings, assumptions and simplifications, there will be uncertainties in different aspects of the study. LCA is usually being used at the design phase of the project to help the decision maker come up with the decisions that are more environmental friendly. In this phase of the project, lots of uncertainties exist due to conceptual design of the building. Knowing these uncertainties can help the decision maker to process outcomes of LCA instead of working with the mere outcomes.

Uncertainties exist in the 3 fundamental parts of the analysis, goal and scope, Inventory analysis, and impact assessment. For instance, a system boundary is assumed for this study. In this phase we disregarded the phases before site preparation and demolishing the previous building; however, demolishing can significantly affect the environmental impacts. An assumption was made for the service life of the project, however, there is a great uncertainty regarding maintenance of the building. Even the maintenance cycle involves some uncertainties.

In the data collection phase, doing the quantity take off involves some uncertainties. For instance using the On Screen take off software and extracting data from the 2D files is not completely accurate. In Addition, there were some missing data that some assumptions had to be made for that. These can bring up some uncertainties in this phase of the project.

Having these inputs, IE will come up with some results that contain some uncertainties. For instance, Column and Beam sizes are designed by IE based on some rough information provided as input to IE. Looking at the BOM and impact category results in previous sections, it is clear that IE calculates the environmental impacts from BOM which creates; however, there is a great uncertainty about that. There is a possibility that the software over designed the structural elements which makes the decision maker hesitant about the reliability of the outcomes.

In addition, as IE has a limited list of materials, when the exact material didn’t exist in IE the closest option to that material was chosen. However, these two materials may completely have different environmental impacts.

There are other uncertainties regarding the location of the building, climate, regional differences in environmental sensitivity, IE data base, IE assumptions, interpretation of impacts over time, mistakes, etc.

4.4 Sensitivity Analysis

Sensitivity Analysis can help the decision maker understand changing the amount of which materials in the building have the most effective impact on the environment. By knowing the materials to which impact categories are most sensitive, the decision maker can focus on those materials more, rather than focusing on the whole building. It can help the decision maker to study those materials in greater details and try to reduce the environmental impacts of it. The decision maker can reduce the environmental impact of that material by changing the material to a more environmental friendly material. Changing the transportation mode or the supplier to reduce the environmental impact of transportation can help as well. In some cases, even changing one raw material in the product can cause a significant reduction in negative environmental impacts.

For Pharmaceutical building five different materials were selected and their amounts were increased by 10% in order to study if the impact categories are sensitive to these changes. It was tried to choose the materials that is thought are used the most in the building. These materials are Concrete 30 MPa (flyash avg), Rebar, Rod, Light Sections, Glazing Panel, Galvanized stud, and 5/8" Fire-Rated Type X Gypsum Board. Figure 16 to Figure 20 shows the sensitivity of each impact categories to 10% increase in each of the materials.

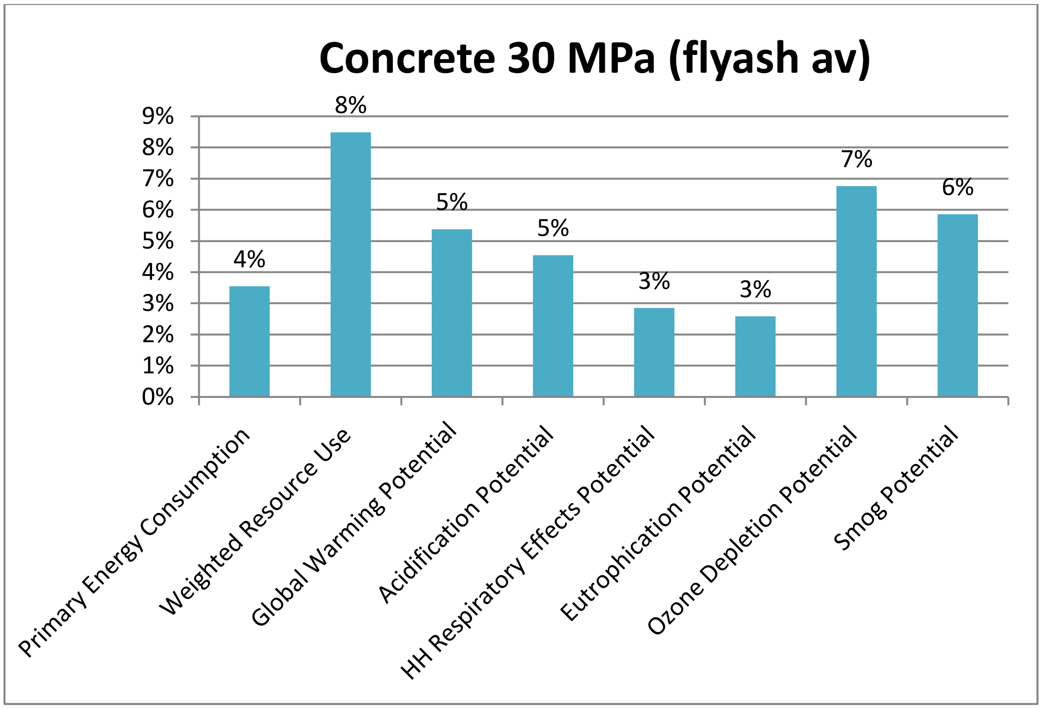

Figure 16 the sensitivity of each impact categories to 10% increase in Concrete 30 MPa (flyash av)

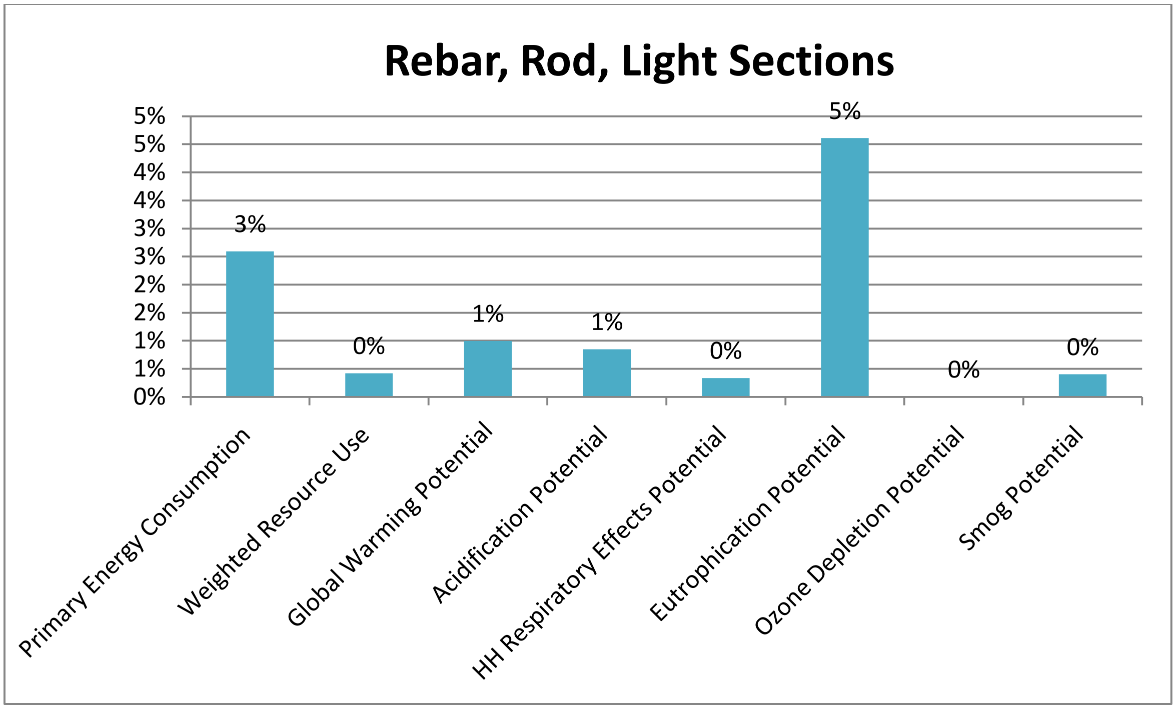

Figure 17 the sensitivity of each impact categories to 10% increase in Rebar, Rod, and Light Sections

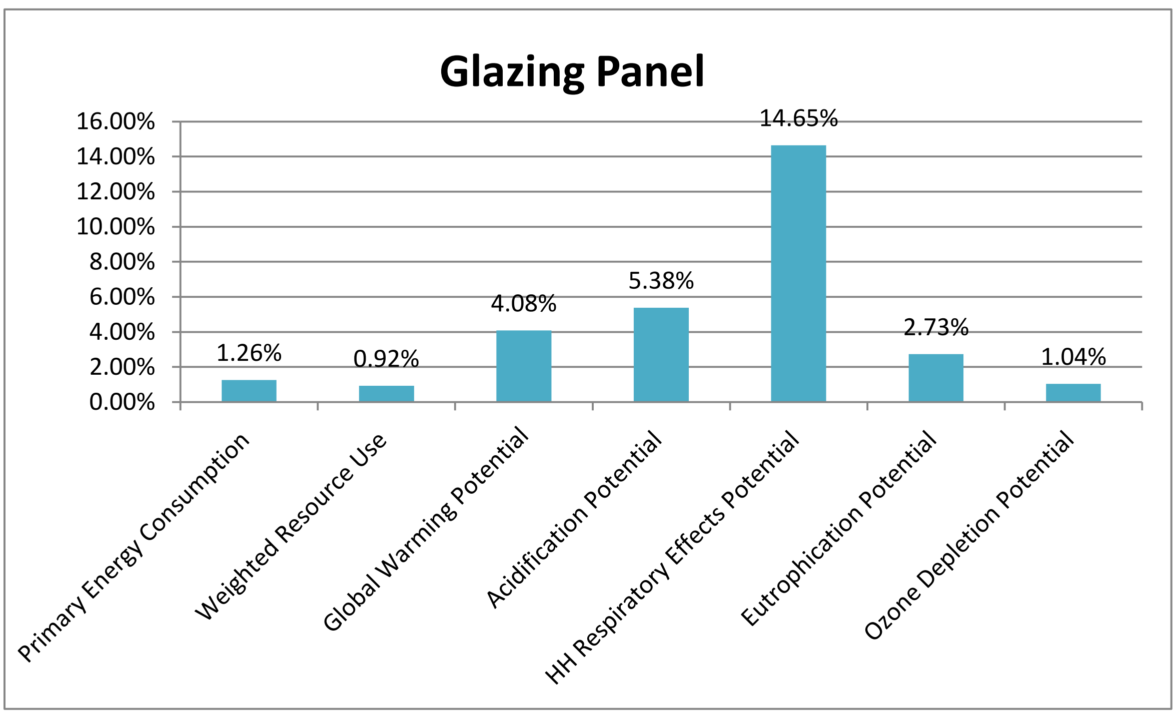

Figure 18 the sensitivity of each impact categories to 10% increase in Glazing Panel

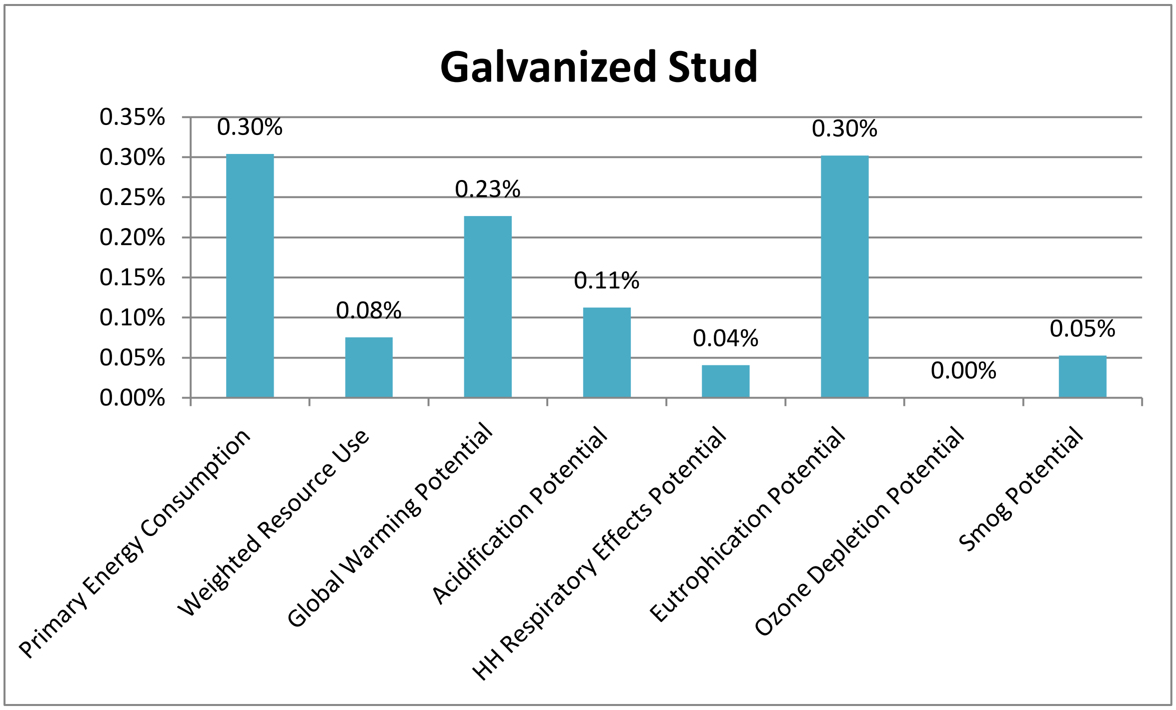

Figure 19 the sensitivity of each impact categories to 10% increase in Galvanized Stud

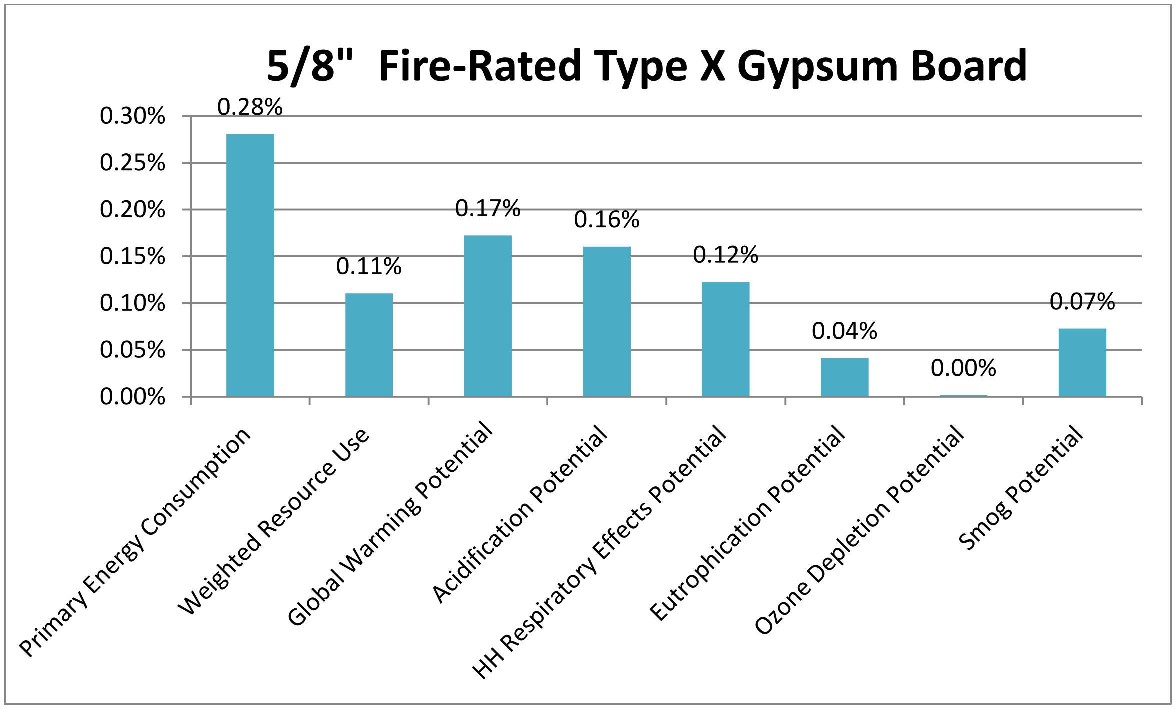

Figure 20 the sensitivity of each impact categories to 10% increase in 5/8" Fire-Rated Type X Gypsum Board

Based on the sensitivity analysis, Concrete 30 MPa (flyash av), Rebar, Rod, Light Sections, and glazing Panel are the materials that needs paying attention as the 10% increase in their quantity makes noticeable differences in most of the impact categories.

In addition, if one specific impact category is the focus, the decision maker can decide on the material that he should focus on, by looking at the sensitivity analysis. For instance, if the purpose is decreasing HH Respitory Effects Potential, glazing panel is the material that he needs to study more in detail.

As a result, in order to reduce the environmental impacts of the building, these three materials are among the materials that the decision maker should focus on. For instance, he can try to substitute concrete with another material that works or changing the envelope or a part of it to another material can also help. If the decision maker can trace back the materials, there is a possibility that by providing them from another source the transportation impacts can be reduced. Using more durable material can also help since it affects the maintenance stage of the project.

It is also observed that the impact categories are not sensitive to Galvanized stud, and 5/8" Fire-Rated Type X Gypsum Board. Therefore, changing them cannot be helpful to the environment.

4.5 Chain of Custody

Among the materials that are highly being used in the building and the environmental impact categories are sensitive to them, curtain panel system was selected for the chain of custody. In this section the materials used in the product should be traced back to the manufacturer and to the raw material extraction. For this purpose, the construction manager of the project (Ledcor Co.) was contacted via phone call. After explaining the purpose of the study, the company gave the site’s phone number. Calling to the site, they asked for an email to be written to them requesting the information about manufacturer. Waiting for a reply, one of the authors went to the site and asked for the manufacturer personally. Intricate Glass Co. name was given as the manufacturer. Trying to contact to intricate glass, they made it clear that the company just installed the curtain system which was provided by manufacturer. Sending an follow up email, they gave the information of the manufacturer which was Inland Glass & Aluminum Co.. After calling the company it took a day to get the required information; however, some parts were missing. The company’s project manager declared that tracing back all the materials that is being used for manufacturing is a complicated time consuming process; therefore, just the main components i.e. glass and aluminum extrusion’s data were provided.

According to the project manager, for aluminum extrusion the materials are extracted in Ferndale Washington and manufactured in Portland Oregon. Glass is manufactured in Minnesota and there is no data on where the raw materials were produced. Then the extrusions and glass come to company's shop in Kamloops and then are shipped to the site. All the transportations are by truck.

Looking at the process to trace back the materials, it is a time consuming process. For curtain walls it took about three to four business days to find these information which is not detailed and complete. Looking at the BOM with 33 different materials, tracing back all these materials seems to be time consuming energy taking process. If all of these materials are going to be traced back one at a time, in ideal situation it will take 132 business days to trace them all back and still it is not that much detailed and complete.

4.6 Building Functions

The building is intended to be Faculty of Pharmaceutical sciences and center for drug research and development which includes teaching, learning, research and community outreach activities. Therefore, different functional area types are defined for that such as classrooms, research labs, offices and etc., Table 11 shows the different functional area types, their assigned gross floor area, and their percentage of total area buildings. It shows that near half of the building is assigned to offices and Study/Research/Prep/Computer lab rooms.

Table 11. Building Functions

Functional Area Type	*Gross Floor Area (ft2)*	*Percentage of Total Building Area*
Classrooms	2,460.59	10.76%
Offices/Office Spaces	5,493.90	24.02%
Testing labs	2,030.38	8.88%
Library	287.18	1.26%
Study/Research/Prep/Computer lab rooms	6,170.61	26.98%
Storage rooms	38.15	0.17%
Stairwells/Halls/ Atriums	2,913.69	12.74%
Washrooms/ Locker rooms	498.50	2.18%
Mechanical rooms	2,225.00	9.73%
Auditorium/ Lecture Halls	753.00	3.29%
Building Total	22,871	

4.7 Functional Unit

Functional unit is a key element in LCA and needs to be clearly defined. It describes and quantifies those properties of the product, which must be present for the studied substitution to take place (Weidema et al. 2004). The main porpose of the functional unit is to have a reference unit to which all the inputs and outputs are referred. It helps to make comparisons between the results of different studies.8

For this study, four different functional units were introduced. The functional units are defined in a way that is believed can present the outputs of study in a clear way and makes it easy to compare with other academic buildings. Each functional unit is defined and the results are shown as follows:

[8] http://www.stonecourses.net/environment/goallca.html

4.7.1 Per generic post-secondary academic building square meter constructed

The building total impact results are divided by the gross floor area and the results are shown in Table 12. This functional unit gives the readers an idea that every square meter of an academic building has these environmental impacts.

Table 12 Impact category results based on per generic post-secondary academic building square meter constructed

Impact Category	*Results*	*Functional Unit*
		per generic post-secondary academic building square meter constructed
Fossil Fuel Consumption MJ	107,824,522.73	4,714.46
Weighted Resource Use kg	55,997,007.97	2,448.38
Global Warming Potential (kg CO2 eq)	10,360,296.65	452.99
Acidification Potential (moles of H+ eq)	4,124,439.69	180.33
HH Respiratory Effects Potential (kg PM2.5 eq)	41,426.92	1.81
Eutrophication Potential (kg N eq)	5,157.14	0.23
Ozone Depletion Potential (kg CFC-11 eq)	0.02	0.00
Smog Potential (kg NOx eq)	49,908.81	2.18

4.7.2 Per specific post-secondary academic building square meter constructed

For this functional unit the total building results are propagated between different functional area types of the building considering their area percentage of the whole building. There is a designated functional unit for every impact category and the proportion of this impact category is defined by the functional unit. Table 13 shows the results for this functional unit.

Table 13 Functional unit per specific post-secondary academic building square meter constructed

	Functional unit per specific post-secondary academic building square meter constructed							
Functional area type	***Fossil Fuel Consumption MJ***	***Weighted Resource Use kg***	***Global Warming Potential (kg CO2 eq)***	***Acidification Potential (moles of H+ eq)***	***HH Respiratory Effects Potential (kg PM2.5 eq)***	***Eutrophication Potential (kg N eq)***	***Ozone Depletion Potential (kg CFC-11 eq)***	***Smog Potential (kg NOx eq)***
Classrooms	507.208	263.411	48.735	19.401	0.195	0.024	7.122E-08	0.235
Offices/Office Spaces	1,132.473	588.133	108.813	43.319	0.435	0.054	1.59E-07	0.524
Testing labs	418.528	217.356	40.214	16.009	0.161	0.020	5.877E-08	0.194
Library	59.197	30.743	5.688	2.264	0.023	0.003	8.312E-09	0.027
Study/Research/ Prep/ Computer lab rooms	1,271.966	660.576	122.217	48.654	0.489	0.061	1.786E-07	0.589
Storage rooms	7.864	4.084	0.756	0.301	0.003	0.000	1.104E-09	0.004
Stairwells/Halls/ Atriums	600.607	311.916	57.709	22.974	0.231	0.029	8.434E-08	0.278
Washrooms/ Locker rooms	102.757	53.365	9.873	3.931	0.039	0.005	1.443E-08	0.048
Mechanical rooms	458.646	238.191	44.069	17.544	0.176	0.022	6.44E-08	0.212
Auditorium/ Lecture Halls	155.218	80.610	14.914	5.937	0.060	0.007	2.18E-08	0.072

4.7.3 Per generic post-secondary academic building cubic meter constructed

The previous mentioned functional units do not consider the hight of each floor and as a result the height of the building. In order to take this factor into account, the impact category results are shown per generic post-secondary academic building cubic meter constructed. For this functional unit, the impact category results were divided by the volume of the building. In order to obtain building's volume the average area of the floors is multiplied by the height of the building. Table 14 shows the results for this functional unit.

Table 14 Functional unit- per generic post-secondary academic building cubic meter constructed

Impact Category	*Results*	*Functional Unit*
		per generic post-secondary academic building cubic meter constructed
Fossil Fuel Consumption MJ	107,824,522.73	862.78
Weighted Resource Use kg	55,997,007.97	448.07
Global Warming Potential (kg CO2 eq)	10,360,296.65	82.90
Acidification Potential (moles of H+ eq)	4,124,439.69	33.00
HH Respiratory Effects Potential (kg PM2.5 eq)	41,426.92	0.33
Eutrophication Potential (kg N eq)	5,157.14	0.04
Ozone Depletion Potential (kg CFC-11 eq)	0.02	1.21E-7
Smog Potential (kg NOx eq)	49,908.81	0.40

4.7.4 Per Dollar spent on the investment

This functional unit captures environmental impacts of the building based on the project's investment. If the projects budget is spent in a more conscious manner of the environment, every dollar spent on the project can decrease the environmental impact.

Impact Category	*Results*	*Functional Unit*
		per dollar spent on the investment
Fossil Fuel Consumption MJ	107,824,522.73	6.96E-01
Weighted Resource Use kg	55,997,007.97	3.61E-01
Global Warming Potential (kg CO2 eq)	10,360,296.65	6.68E-02
Acidification Potential (moles of H+ eq)	4,124,439.69	2.66E-02

Impact Category	*Results*	*Functional Unit*
		per dollar spent on the investment
HH Respiratory Effects Potential (kg PM2.5 eq)	41,426.92	2.67E-04
Eutrophication Potential (kg N eq)	5,157.14	3.33E-05
Ozone Depletion Potential (kg CFC-11 eq)	0.02	9.77E-11
Smog Potential (kg NOx eq)	49,908.81	3.22E-04

5 Conclusion

The purpose of this study was to do a life cycle assessment of the UBC Faculty of Pharmaceutical Sciences and Center for Drug Research and Development. This building is a new building which is now under construction. The goal and scope of the study is determined for the first step of the study. Quantity take off from foundations, walls, floors, beams and columns, and envelope system was done using the structural and architectural drawings by On Screen Take off software.

In order to model these assembly types in IE, some assumptions and adjustments have been made. All these assumptions are clearly declared so that readers would have a good understanding of the outcomes and help them to utilize them. The Bill of material was extracted from the IE and five materials that are being used the most were chosen for further studies. These five materials are concrete 30Mpa, 5/8" Fire-Rated Type X Gypsum Board, glazing panels, galvanized studs and rebar rod and light sections.

The results from IE which is based on eight impact categories during the manufacturing, construction, maintenance, and end of life phases, were shown and discussed via tables and charts. As the results were shown by different building assemblies, it can be seen which assembly has the main contribution to each impact category. For comparison purposes, four functional units were defined and calculated as well.

A sensitivity analysis was also done for the five materials mentioned before to see the sensitivity of impact categories to 10% increase in these materials. It was concluded that concrete 30MPa, Rebar, Rod, and light section, and glazing panels are the materials that need to be studied in more details to decrease the impact category results in general.

This study did an LCA on Pharmaceutical building; however, the assessment was general. For having results in greater details and accuracy, more building assemblies should be modeled in IE such as flooring and finishing. For decision making purposes, the sensitivity analysis should be done in a more comprehensive way by considering almost all materials that is being used in the building. Therefore, the decision maker has more options to decrease the environmental impacts of the building.

6 References

- Jane C. Bare, 2002, “The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts”, Journal of Industrial Ecology, Volume 6, Issue 3-4, 97-68
- BO Wedema, 2004, “The product, functional unit and reference flows in LCA”, Danish environmental protection Agency, Environmental news, No.70
- http://www.stonecourses.net/environment/goallca.html

7 Authors segment

“Nowadays, **sustainability** is a controversial issue among engineers, environmentalists, and politicians. Individuals are concerned about the environmental impacts of the products they consume, the buildings they live in, and their everyday actions and do everything possible to minimize the environmental impacts of their actions to their highest possible extend. Engineers and environmentalists play an important role in reducing the environmental impacts of new projects, such as new buildings. As an engineer, sustainability and being green is important to me. CIVL 498E course description got my attention and motivated me to learn more about new tools use to implement sustainability practices. Throughout this course, I have learned how to attain quantity takeoffs from On-Screen Takeoff as well as BIM. Also, I have learned how to assess different materials’ impacts through using Athena Impact Estimator and performing Sensitivity Analysis.

I have found all these new tools and software useful for future to assess and reduce environmental impacts in designing and construction phases of new projects.”

Mahshid Hashemi

“Being involved with Building Information modeling (BIM), I was enthusiastic to see how BIM can Leverage LCA as both areas are evolving in recent years. Going through each step in LCA, I was sure that BIM can help LCA to come up with the results in a faster more accurate manner.

For instance, using On Screen take-off for doing QTO was a time consuming, confusing, error prone task. However, using the 3D model for QTO purposes is a faster more accurate process. In decision making phase, using 3D model can help the decision maker to evaluate his options faster.

One of the most challenging parts in the impact estimator is that the assemblies should be modeled manually in the software. Considering the size of the projects that LCA is usually done for, makes it clear that the inputting phase is a time consuming prone to error process. There is a need to link the 3D model to IE so that the required information flows automatically from the 3D model to IE. In this way different options can be tested in a faster more accurate manner.”

Helia Amiri

Appendix A

Appendix B

PROVISIO

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

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

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

Life Cycle Assessment of UBC Faculty of Pharmaceutical Sciences Building

CIVL 498E Final Report

Helia Amiri

Mahshid Hashemi

April 2012

Abstract

The Life Cycle Assessment of the UBC Faculty of Pharmaceutical Sciences and Center for Drug Research and Development was performed in order to evaluate its environmental impacts. This building is currently under construction and in order to attain the most reliable data and to evaluate their performance and impacts on the environment, more accurate data collection is required. Which itself requires more accurate and up to date drawings and models. This project was done through modeling the building using On-Screen Takeoff and Athena Impact Estimator software. Since this building is under construction, BIM model was found helpful and more updated than structural and architectural drawings and was used as a supplement to these drawings.

According to the Bill of Materials obtained from On-Screen Takeoff and Athena Impact Estimator, five most significant materials of this building were recognized to be concrete 30Mpa, 5/8" Fire-Rated Type X Gypsum Board, glazing panels, galvanized studs and rebar rod, and light sections.

The output from the Impact Estimator (IE) is a list of impact category during the manufacturing and construction phases to the end-of-life stage of the building. The results of the study in terms of the impact categories are as follow:

- Global warming potential: 1.04E+07 *kg* CO_2 *eq*
- Ozone layer depletion: 1.51E-02 *kg CFC-11 eq*
- Acidification potential: 4.12E+06 *moles of* H^+ *eq*
- Eutrophication potential: 5.16E+03 *kg N eq*

- Smog potential: 4.99E+04 *kg NOx eq*
- Human health respiratory effects: 4.14E+04 *kg PM2.5 eq*
- Weighted resource use: 5.60E+07 *ecologically weighted kg*
- Fossil fuel use: 1.08E+08 *MJ*

After performing Sensitivity Analysis on the five most common materials in the building and evaluating their effects on each impact category, walls show great impacts on global warming, ozone layer depletion, acidification potential, smog potential, human health respiratory effects, and fossil fuel use more than other assemblies. Also, columns and beams have the major contribution to eutrophication potential impact category since they mainly consist of concrete and rebar. Floors play the main role in impact potential of weighted resource use.

Table of Contents

1 Introduction

UBC Faculty of Pharmaceutical sciences and center for drug research and development is located at the corner of Wesbrook Mall and Agronomy Road on the UBC Point Grey Campus. The Pharmaceutical building with a gross area of 22,871 square meter houses for the first time under one roof all the teaching, learning, research and community outreach activities of the Faculty of Pharmaceutical Sciences. The six storey building provides teaching and learning spaces including lecture halls and classrooms and seminar rooms, as well as study spaces for students. The building also includes a pharmacist clinic, three floors of research spaces, and a data center.

It is a 155 million dollar project with the Leadership in Energy and Environmental Design (LEED) Gold certificate. The project is started in mid 2010 and is intended to be finished in summer 2012.

The Pharmaceutical building is a reinforced concrete building with the major structural and envelope characteristics outlined in the table below:

Table 1 Building Characteristics of Pharmaceutical Building

Structure	Concrete columns supporting concrete suspended slab
Floors	Basement: Concrete SOG, Level -1 interstitial: Steel joist floor, Other levels: Concrete suspended slab
Exterior walls	Curtain wall
Interior walls	Concrete cast in place walls, gypsum on steel stud walls, Metal clad wall, Masonry partition wall, and Curtain wall
Window	All the exterior walls are curtain walls
Roof	Concrete suspended slab with two SBS sheet membrane, protection board and two layers of rigid insulation
Mechanical	Heat Exchange System

2 Goal & Scope

In accordance with the ISO 14040 and 14044 standards, this report will provide sections to describe the Goal and Scope. The following Goal and Scope section outlines the details of the LCA study that was carried out on the Pharmaceutical Building Project.

The Goal & Scope is critical to documenting the context and guiding an LCA study's execution. The purpose of defining the Goal of the study is to unambiguously state the context of the study, whereas the Scope details how the actual modeling of the study was carried out.

For this Pharmaceutical Building LCA study report, the format immediately below has been used to unambiguously outline the details of the parameters outlined in ISO 14040 and 14044.

Parameter Name

Parameter definition.

Details of how this item is defined for the Pharmaceutical Building LCA study.

This format has been followed throughout the Goal & Scope in order to provide the audience with an explanation each parameter and transparently state how it is defined for the Pahrmaceutical LCA study.

2.1 Goal of Study

The following are descriptions for a set of parameters which unambiguously state the context of the Pharmaceutical Building LCA study.

Intended application

Describes the purpose of the LCA study.

This LCA study will be used to evaluate the environmental impacts of the new building.

Reasons for carrying out the study

Describes the motivation for carrying out the study.

The report itself is an educational asset to help disseminate education on LCA and help further the development of this scientific method into sustainability in building construction practices at UBC and the green building industry as LCA is rapidly gaining acceptance at all scales of sustainable construction standards and corporate social responsibility policy.

Intended audience

Describes those who the LCA study is intended to be interpreted by.

The results of this study are to be primarily communicated to the public. In addition to the general public, the LCA report is intended to be communicated to industry and governments groups observing and involved in green building, as LCA is an emerging topic of significance in this area.The results would also be helpful for projects stake holders such as Construction Manager (Ledcor Construction), designers team (Stantec Consulting, Core Group Consultants, GHL Consultants, Morrison Hershfield) and the Architects (Saucier + Perrotte Architects, Hughes Condon Marler Architects)

Intended for comparative assertions

State whether the results of this LCA study are to be compared with the results of other LCA studies.

The results of this LCA study are not intended for comparative assertions. However; Its a benchmark so it can be used to drive to development performance based green design.

2.2 Scope of Study

The following are descriptions for a set of parameters that detail how the actual modeling of the study was carried out.

Product system to be studied

Describes the collection of unit processes that will be included in the study.

A unit process is a measurable activity that consumes inputs and emits outputs as a result of providing a product or service. The main processes that make up the product system to be studied in this LCA study are, the manufacturing of construction products (Figure 1), the construction of a building (Figure 2),maintenance which is a combination of demolition, manufacturing and construction itself, Operating Energy (Figure 3) and the demolition of it (Figure 4**Error! Reference source not found.**. These three processes are the building blocks of the LCA models that have been developed to describe the impacts associated with the Pharmaceutical Building. The unit processes and inputs and outputs considered within these three main processes are outlined below.

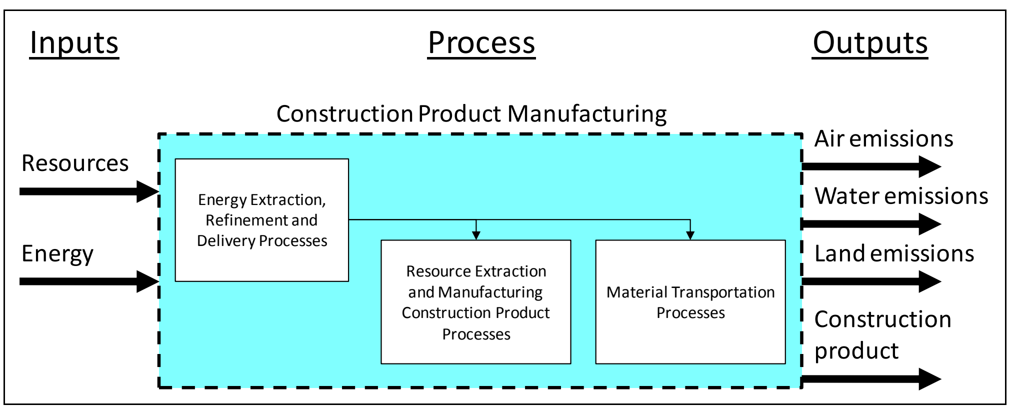

Figure 1- Generic unit processes considered within Construction Product Manufacturing process by Impact Estimator software.

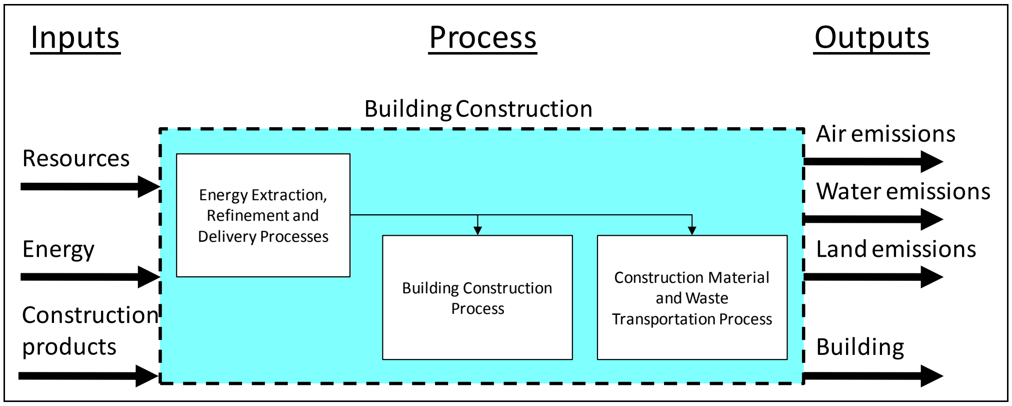

Figure 2- Generic unit processes considered within Building Construction process by Impact Estimator software.

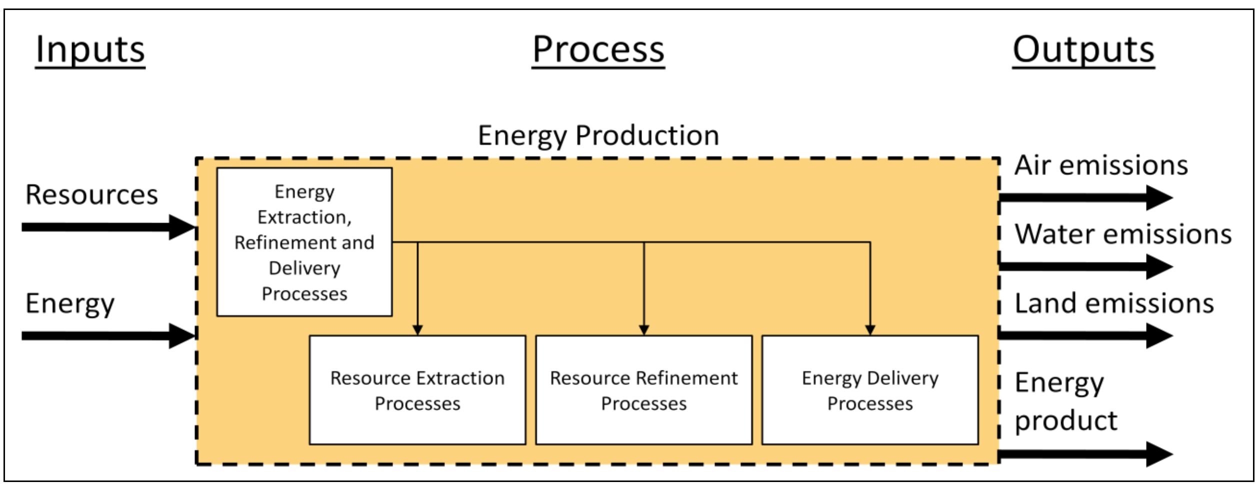

Figure 3- Generic unit processes considered within Energy Production process by Impact Estimator software.

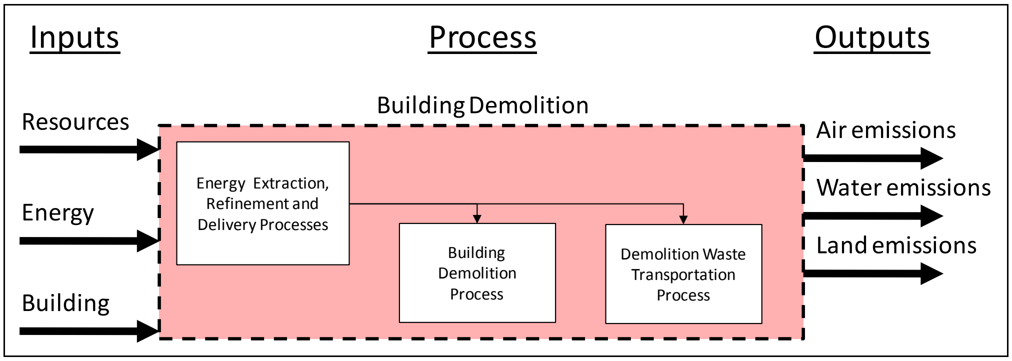

Figure 4- Generic unit processes considered within Building Demolition process by Impact Estimator software.

As seen in the above figures, the inputs and outputs occurring at the various stages in a buildings life cycle are captured. The construction product manufacturing, building construction processes, energy production processes, building maintenance process, and the building demolition unit process capture the capture the cradle to grave process. The organization of these processes into the product systems to describe the environmental impacts of the new building requires the definition of a system boundary. Thus, the product system studied in this Pharmaceutical Building LCA study is further defined in the system boundary section below.

System boundary

Details the extent of the product system to be studied in terms of product components, life cycle stages, and unit processes.

This study includes the construction products used to create their structures and envelopes. This indicates that product components must be defined the materials within the products studied.

The material product components (i.e. building assemblies) that were included from the products (i.e. buildings) are the footings, slabs on grade, walls, columns and beams, roofs, as well as all associated doors and windows, gypsum board, vapour barriers, insulation, cladding, roofing, and curtain walls. These material product components are in turn assemblies of construction products.

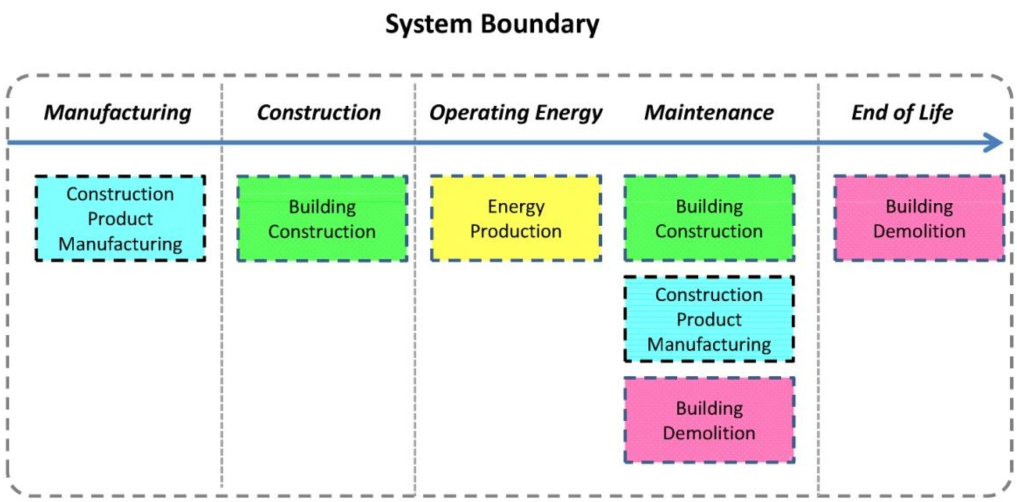

Figure 5- System boundary for Renovation and Building New scenarios.

The life cycle stages considered in the Pharmaceutical Building include those spanning from cradle-to-grave. The Process begins from site preparation, starting with resource extraction and manufacturing of construction products, the building construction process then it goes to the maintenance and operating energy phase and it ends with building demolition process. shows the system boundary defined for this project.

Functions of the product system

Describes the functions served by the product focused on in the LCA study.

A description of the Pharmaceutical building's major functions hase been outlined in the Introduction of this report.

Functional unit

A performance characteristic of the product system being studied that will be used as a reference unit to normalize the results of the study.

The functional units used in this study to normalize the LCA results for the Pharmaceutical Buildings include:

- *per generic post-secondary academic building square meter constructed*
- *per specific post-secondary academic building square meter constructed*
- *per generic post-secondary academic building cubic meter constructed*
- *Per Dollar spent on the investment*

Further discussion of these functional units and their application are contained in the Impact Assessment sub-section under Functions and Impacts.

Allocation procedures

Describes how the input and output flows of the studied product system (and unit processes within it) are distributed between it and other related product systems.

The problem of allocation arises in three situations – i) when a process produces more than one product, ii) a waste treatment process collectively treats multiple wastes products and iii) when materials are recycled or reused in subsequent life cycles. An allocation problem arises in these situations because the input and output flows from the processes must be shared amongst the products and subsequent life cycles.

In this study, the cut-off allocation method was used, which entails that only the impacts directly caused by a product within a given life cycle stage are allocated to that product. The LCA starts from extracting the raw material and doesn't include the process that the raw material is created and ends with the demolition phase and doesn't include the treatment of the demolished materials.

Impact assessment methodology and categories selected

State the methodology used to characterize the LCI results and the impact categories that will address the environmental and other issues of concern.

The primary impact assessment method used in the Pharmaceutical Building LCA study was the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), developed by the US Environmental Protection Agency (US EPA). The impact assessment methodology developed by the Athena Institute was also used to characterize weighted raw resource use and fossil fuel consumption.

The impact categories selected and the units used to express them (i.e. category indicators) are listed below.

- Global warming potential – kg CO_2 equivalents
- Acidification potential – H^+ mol equivalents
- Eutrophication potential – kg N equivalents
- Ozone depletion potential – kg CFC^{-11} equivalents
- Photochemical smog potential – kg NOx equivalents
- Human health respiratory effects potential – kg $PM_{2.5}$ equivalents
- Weighted raw resource use – kg
- Fossil fuel consumption – MJ

Short descriptions of each of these impact categories are provided in the Impact Assessment sub-section in Results and Interpretation.

Interpretation to be used

Statement of significant issues, model evaluation results and concluding remarks.

Analysis and discussions of uncertainty, sensitivity, and functional units of this LCA study are contained in the Results and Interpretation section of this report, whereas concluding remarks are contained in the Conclusion.

Assumptions

Explicit statement of all assumptions used to by the modeler to measure, calculate or estimate information in order to complete the study of the product system.

As with data sources, there were two main areas where assumptions were integrated, which include – performing materials takeoffs of building assemblies and those contained within the Impact Estimator.

The details of the methods used in completing the material take offs on the building drawings are summarized in the Model Development section of this report.

All of the inputs and assumptions associated with interfacing these takeoffs with the Impact Estimator are documented in the Input Document (**Error! Reference source not found.**) and the Assumptions Document (**Error! Reference source not found.**). Assumptions were typically required in the development of building assembly information due to missing information as well as limitations in construction product LCI data and assembly characteristics in the Impact Estimator.

Assumptions regarding the completion of take offs to estimate material use, referenced LCI data and transportation networks have all been developed by the Athena Institute and are built into the Impact Estimator version 4.1.14 12 This information is proprietary; however, parts can be accessed through the inner workings report found on the Athena Institute webpage.[1]

Value choices and optional elements

Details the application and use of normalization, grouping, weighting and further data quality analysis used to better understand the LCA study results.

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[1] –V4.1 Software and Database Overview

http://www.athenasmi.org/wp-content/uploads/2011/10/ImpactEstimatorSoftwareAndDatabaseOverview.pdf

Value choices and optional elements were not included in this study due to limited time and resources; however, this report does provide sufficient documentation for its audience to carry out these types of analyses.

Limitations

Describe the extents to which the results of the modeling carried out on the product system accurately estimate the impacts created by the product system defined by the system boundary of the study.

The following limitations should be considered when interpreting the results of this LCA study:

System Boundary – Any of the impacts created or avoided through the reuse, recycling or waste treatment of the construction or demolition wastes emitted were outside the scope of this study.

Data Sources and Assumptions – This LCA study used original architectural and structural drawings obtained to develop information on the building assemblies in the partial construction of the Pharmaceutical Building. The resulting LCA models are specific to this building as their bills of materials reflect its unique design. Furthermore, the life cycle inventory flows and their characterization reflect averages of industry processes and their impacts for North America. This is due to the fact that those industries engaged in the North American construction market are currently not providing this LCI data. Furthermore, it was not possible to regionalize the impacts of processes and their inventory flows due to time and resource constraints in conducting this study.

Data quality requirements

Qualitative and quantitative description of the sourced data used in the study including its age, geographical and technological coverage, precision, completeness, reproducibility and uncertainty.

The sources of data used in the development of this LCA study include those used to estimate results for the bill of materials, life cycle inventory (LCI) flows and the characterization of LCI flows.

Bill of materials - Architectural and structural drawings were obtained to develop information on the building assemblies. Building Information Modeling (BIM) also contributed information were information was either missing or unclear in the drawings. The precision of the quantity take offs does rely somewhat on the quantity takeoffs built into the Impact Estimator, as the quantity take offs from the drawings are input and completed by the Impact Estimator. However, the use of the Impact Estimator does enable these results to be reproduced due to all results being documented in the Inputs and Assumptions Documents contained in Appendix A and B in this report.

LCI flows – The Athena LCI Database was the source of LCI data. The quality of the data and modeling assumptions used to develop the Athena LCI Database (which is built into the Impact Estimator) was outside the time and resource constraints of this study. However, some of this information can be accessed through the Athena Institute webpage's Software database overview and the LCI Databases [2], [3]. Generally speaking, this database is specific to the current

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[2] http://www.athenasmi.org/our-software-data/lca-databases/

North American context, and thus does create some geographic and temporal limitations on this study. For instance, i) The construction product manufacturing as well as fuel refining and production LCI data is based on North American averages ii) The transportation matrix that estimates distances and modes for construction product transportation as well as construction and demolition wastes is specific to Vancouver, British Columbia iii) The LCI data and modeling parameters in the Impact Estimator were developed by the Athena Institute to reflect current circumstances and technologies.

Characterization factors – Documentation of the US EPA TRACI impact assessment method can be found on the US EPA website[4], and documentation for the development of the weighted resource use impact category can be found on the Athena Institute webpage[5]. Generally speaking, this method characterized LCI flows to reflect their potential to cause damage on average in North America. Qualitative discussion of the uncertainties present in the impact assessment results are contained in this report in the Impact Assessment sub-section of Results and Interpretation.

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[3] The Inner Working of the Impact Estimator for Buildings: Transparency Document - http://www.athenasmi.org/tools/impactEstimator/innerWorkings.html

[4] US EPA TRACI documentation - http://www.epa.gov/nrmrl/std/traci/traci.html

[5] Weighted resource use impact category development - http://www.athenasmi.org/wp-content/uploads/2011/10/16_ECC_Impacts_of_Resource_Extraction.pdf

Type of critical review

A review of the methods, data, interpretations, transparency, and consistency of the LCA study.

A critical review has not been carried out in the study; however, every effort has been made to be transparent about how the LCA study was developed.

Type and format of the report required for the study

Statement of the type and format followed by the report.

This report followed the final report outline provided by Rob Sianchuk - the instructor of the LCA course this project was carried out under in the UBC Civil Engineering department.

3 Model development

3.1 Structure and Envelope

3.1.1 Material Takeoff Development

The material takeoffs have been done by using software called On-Screen Takeoff. This software can do quantity takeoffs from 2D drawings with a great accuracy. The structural and architectural drawings were used as the main source of information for quantity takeoffs; however, in case of lack of information, 3D models were used in conjunction to the drawings.

There are three types of conditions in On-Screen Takeoff: Linear Condition, Count Condition and Area Condition. Linear condition is for lineal elements such as walls, strip footings. To measure surface areas such as floor, opening sizes are measured via area condition. For counting objects such as footings or windows, count condition is being used.

All assembly types are organized in different layers in order to have easier access to data for different levels. For instance, having same type of partition wall on different level, the partition wall is measured in different levels as different conditions. In this case, one can understand how long of this partition wall is available in different levels. As a result, comparing different options for IE would be easier.

Incomplete information was one of the challenges that arose during the quantity takeoff. In order to overcome this issue, 3-D model was used as the first step to find more detailed and accurate information. If the issue was not solved using the 3-D model, the next step that was taken was talking to the site personnel and finally making an assumption if no information was found. All the assumptions, however, have been fully explained in Appendix B.

3.1.2 Material Takeoff Assumptions

Foundation

Foundation system of the building consists of concrete slab on grade (SOG) and concrete footings. Different types of footings such as spread footings, strip footings, and retaining wall foundations were used in this project. The footings can be found in the structural drawings. For the entire project, the concrete percentage of flyash is set to average in the Impact Estimator as no information was available on the drawings and 3-D models. The thickness of SOG is 150mm; however, due to IE limitations, it is modeled as a 200mm SOG and the required adjustments were made to the length and width in order to have equal amount of concrete.

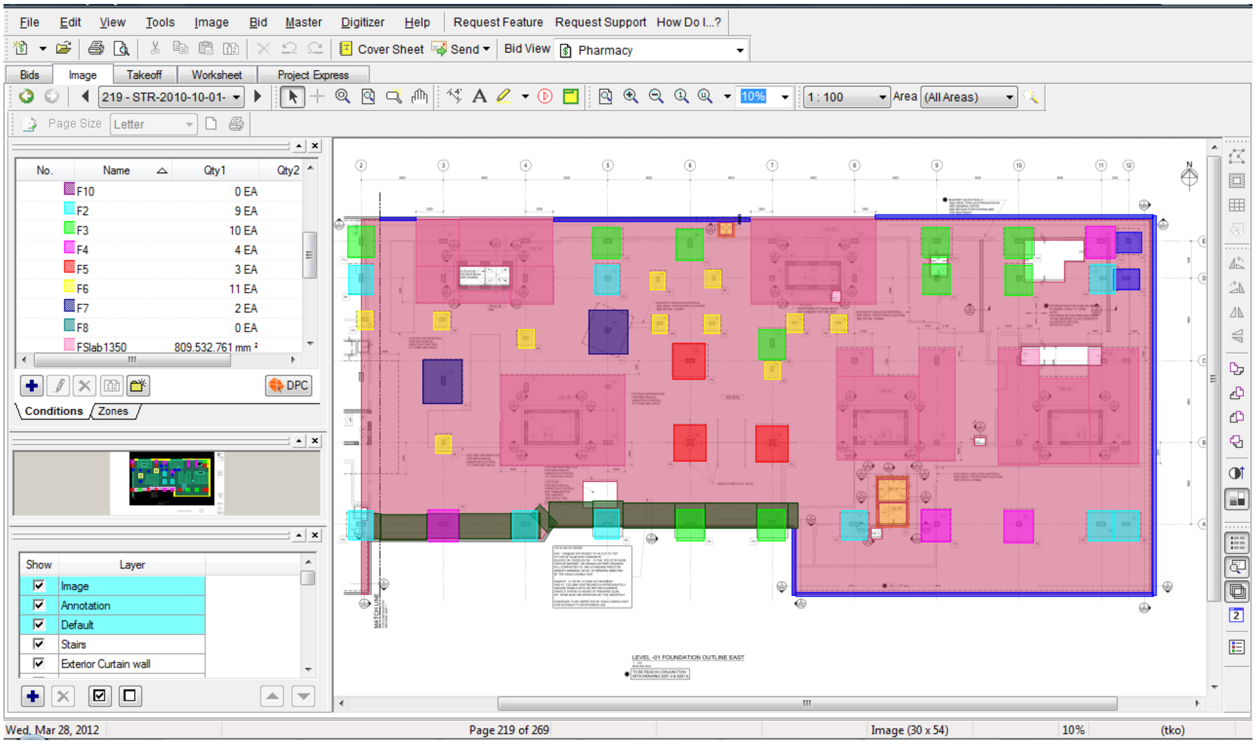

Figure 6 Quantity take off for foundation system

As IE has a limitation of 500 mm thickness for the footings, the thickness of those footings that was more than 500mm was set to 500 mm and the area is changed to have the same volume of concrete. Moreover, as IE has certain concrete strengths and rebar sizes, the actual values of strength and rebar size of footings have been rounded accordingly in order to compensate reinforced concrete strength.

The cross sections of stepped footings were measured using area condition and assuming the constant concrete volume and thickness limitations. They were modeled as rectangular footings. Concrete stairs were modeled as footings using area condition with an average of stair thickness.

Walls

This building consists of several wall types including cast in place, metal clad wall, masonry partition wall, and steel stud and curtain walls. Linear takeoffs were performed on the architectural drawings. As the height of each level varies, walls were categorized into different groups based on their level.

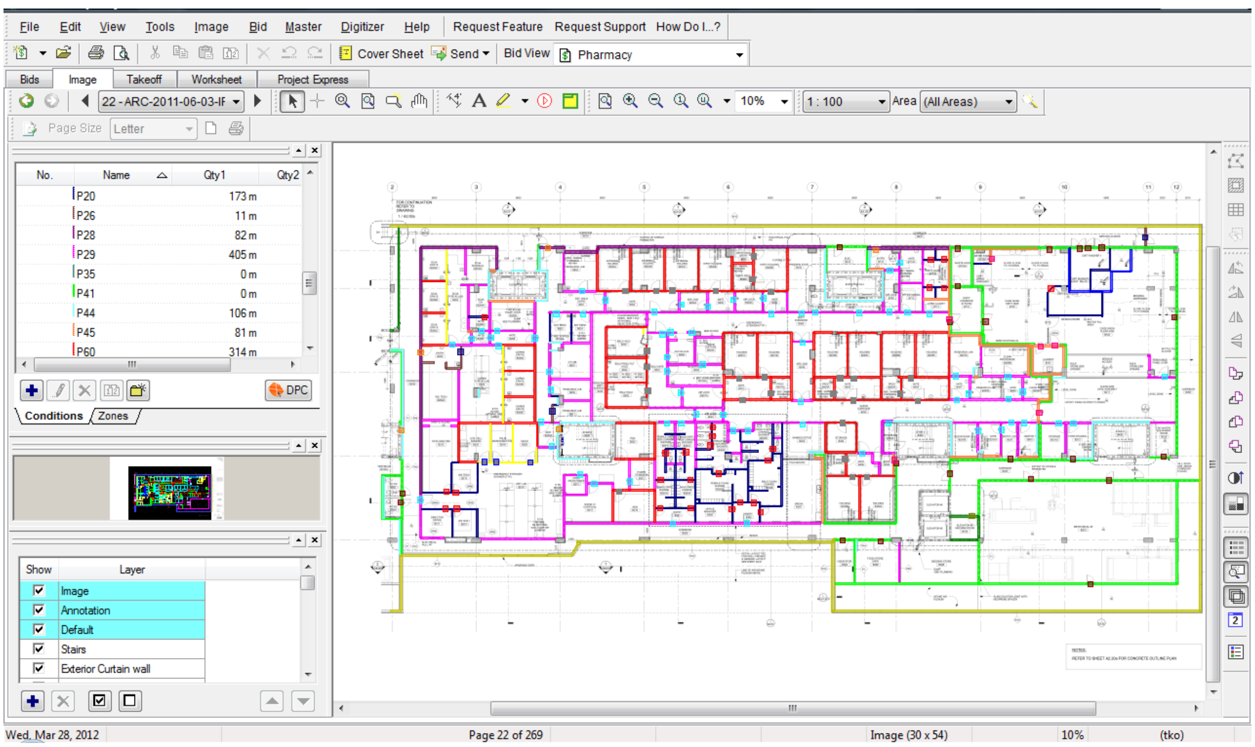

Figure 7 A sample of Quantity take off for wall assemblies

Due to thickness restriction of 200mm and 300mm in the IE, all of the walls required length adjustments to accommodate this limitation. Their length was reduced by a factor while keeping the volume constant and thickness at 200mm or 300mm. Some other assumption has been made, such as considering Polystyrene Extruded as the closest surrogate for Waterproof Membrane. Research shows that Dens Glass Gold Sheathing is essentially a fiberglass covered gypsum board that is also reinforced with glass fibers. This combination provides a product that is dimensionally stable, resistant to fire. This material is not an option in the IE, so it was not counted towards our results from IE. This is the same case for Zinc walls.

Moreover, some materials such as Galvanized Steel Z Bar are not an option under Wall Assembly in IE; thus, they have been categorized under Extra Basic Material as Galvanized Sheet.

According to the architectural drawings, masonry partition walls have unknown rebar size and it has been assumed to have the minimum rebar of #10. Also, based on the observation of drawings, all interior doors are assumed to be Hollow Core Wood interior door.

Columns and Beams

Count conditions were used on structural drawings to determine the number of columns and beams on each floor. The inputs to the IE are number of columns, number of beams, bay size, supported span, floor to floor height, and live load. The size of columns and beams are calculated automatically by IE based on these inputs.

Some assumptions have been made in order to accommodate the bay size limitation of range 3.05m to 12.20m in the IE. Also, based on structural drawings, some levels have varying live load. As the IE accepts one input for each level, the live load that covers most of the floor area is assumed to be the live load of the entire floor and neglect the live load that covers less area compare to the other one.

Floors

Takeoffs were performed on the structural drawings using area condition. Some adjustments have been made to the floor width in order to accommodate the span size range of 0.0m to 9.75m in the IE. Also, the IE calculates the floor thickness based on concrete strength, floor width, span, live load and flyash content. Floor width was calculated from the area divided by the span and the concrete flyash content was assumed to be average for the entire floor measurements. The maximum acceptable live load in the IE is 4.8kPa. On some levels the actual value of live load exceeds this limit; thus, it was assumed to be 4.8kPa.

All the levels have concrete suspended slab floor but level -01 interstitial, which has steel joist floor. In the IE, the acceptable span range for steel joist is between 0.0m to 5.5m. As a result, some adjustments have been made to the width by considering the area constant and the span size to the maximum of 5.5m to maintain within the acceptable range.

Roof

The shape of the plan is not a simple rectangle; thus, its width is calculated by using the area obtained from the takeoff and dividing it by the span. The span is assumed to be 40m. The average concrete flyash is assumed and concrete strength is set to be 30mpa.

Research showed that SBS Self-Adhering Base/Ply Sheet is a durable, modified bitumen membrane designed and manufactured to meet industry and code requirements; therefore, in the IE the material is set to Standard Modified Bitumen Membrane 2 ply which is assumed to be the closest surrogate. Also the thickness was adjusted to the minimum acceptable value in the IE. The minimum acceptable live load in the IE is 2.4kPa; thus, the roof live load was assumed to be 2.4kPa. More assumptions have been made for the roof and can be found in details in Appendix B.

Extra Basic Materials

Some materials were not available as an option in the IE; as a result, they were added to the IE under Extra Basic Materials. Example of such these assemblies is W41 that is covered with a layer of zinc. With considering the volume and density of the zinc, its weight was calculated and inputted into IE.

4 Results and interpretation

4.1 Inventory Analysis

4.1.1 Bill of Materials

Inputting all the required information in the IE, it gave a bill of material for all the components that was modeled in the software (Table 2). However, it is believed that comparing these materials in terms of quantities is not a sound comparison because of the different units. Concrete 30 MPa is one of the materials that is being used in the building in large amounts. This is mainly because all of the structural components are made of concrete especially from concrete 30Mpa. The same reasoning can be applied to Rebar, rod and light section material as rebar is used for reinforcing the concrete. In addition, both concrete and rebar have just three different choices in IE; therefore, to model them one should round up or down to one of the options in IE which makes the BOM over or under estimated. As almost all the Building envelope is curtain panel system, this material is one of the most used materials in the building; however, for the entire building envelope just one type of curtain panel system is assumed. In addition, an assumption was made for the percent viewable glazing and percent spandrel panel which can lead to over estimation of the material.

5/8" Fire-Rated Type X Gypsum Board is another material that is used a lot. Most of the interior walls have this kind of material in their assemblies. Furthermore, IE has limited types of gypsum board and in some cases this kind of Gypsum board was the closest choice to what is used in the building.

Another material that is used in large amounts was galvanized stud. This material is mainly used in walls because several types of interior walls were steel stud walls and because of the limited number of steel stud types, rounding was usually done. The steel joist floor in level -1 interstitial had galvanized stud as well.

Table 2 Bill of Materials for the pharmaceutical Building

Connstruction Material	***Units***	***Building Assembly***					***Building Total***
		Foundation	***Wall***	***Floors***	***Columns & Beams***	***Roof***	
5/8" Fire-Rated Type X Gypsum Board	m2	-	51,738.89	-	-	-	51,738.89
5/8" Gypsum Fibre Gypsum Board	m2	-	495.84	-	-	-	495.84
5/8" Moisture Resistant Gypsum Board	m2	-	3,477.91	-	-	-	3,477.91
6 mil Polyethylene	m2	-	-	-	-	4,173.22	4,173.22
Air Barrier	m2	-	3,536.09	-	-	-	3,536.09
Aluminum	Tonnes	-	108.95	-	-	-	108.95
Batt. Fiberglass	m2 (25mm)	-	86,385.89	-	-	-	86,385.89
Cedar Wood Bevel Siding	m2	-	1,921.24	-	-	-	1,921.24
Cold Rolled Sheet	Tonnes	-	1.66	-	-	-	1.66
Commercial(26 ga.) Steel Cladding	m2	-	6,465.94	-	-	-	6,465.94
Concrete 20 MPa (flyash av)	m3	288.02	-	39.62	-	-	327.64
Concrete 30 MPa (flyash av)	m3	3,287.25	2,114.58	8,052.02	3,137.34	1,393.53	17,984.72
Concrete Blocks	Blocks	-	22,850.01	-	-	-	22,850.01
EPDM membrane (black, 60 mil)	kg	-	6,828.27	-	-	-	6,828.27
Extruded Polystyrene	m2 (25mm)	-	8,471.59	-	-	4,091.38	12,562.97
Foam Polyisocyanurate	m2 (25mm)	-	-	-	-	16,486.95	16,486.95
Galvanized Sheet	Tonnes	-	21.91	-	-	-	21.91
Galvanized Studs	Tonnes	-	107.14	40.99	-	-	148.13
Glazing Panel	Tonnes	-	842.22	-	-	-	842.22
Hot Rolled Sheet	Tonnes	-	1.25	-	-	-	1.25
Joint Compound	Tonnes	-	55.60	-	-	-	55.60
Modified Bitumen membrane	kg	-	-	-	-	125,461.99	125,461.99
Mortar	m3	-	436.08	-	-	-	436.08
Nails	Tonnes	-	2.93	-	-	0.73	3.66

Connstruction Material	*Units*	*Building Assembly*					*Building Total*
		Foundation	*Wall*	*Floors*	*Columns & Beams*	*Roof*	
Paper Tape	Tonnes	-	0.64	-	-	-	0.64
Rebar, Rod, Light Sections	Tonnes	9.76	117.47	474.14	1,069.75	73.19	1,744.32
Screws Nuts & Bolts	Tonnes	-	7.99	0.59	11.41	-	19.99
Small Dimension Softwood Lumber, kiln-dried	m3	-	5.00	-	-	-	5.00
Softwood Plywood	m2 (9mm)	-	2,259.86	-	-	-	2,259.86
Solvent Based Alkyd Paint	L	-	25.17	-	-	-	25.17
Water Based Latex Paint	L	-	4,691.87	-	-	-	4,691.87
Welded Wire Mesh / Ladder Wire	Tonnes	6.22	-	-	-	-	6.22
Wide Flange Sections	Tonnes	-	-	-	217.13	-	217.13

4.2 Impact Assessment

The output from impact estimator is a list of impact category identified by US EPA. In this part for each impact category a description is provided using TRACI[6]. Then the results from the impact estimator are provided for each building assembly in different stages of the building and for the whole building as well. As LCA is a cradle to grave assessment, the results for each impact category are shown from manufacturing to end-of-life stage. These impact categories which are based on a midpoint approach are as follow:

4.2.1 Global Warming

Global warming which is categorized as pollution categories refers to the potential increase in the earth's temperature because of green house gases that trap heat

[6] The tool for the reduction and assessment of chemical and other environmental impacts

from reflected sunlight. This is a midpoint metric for calculation of the potency of greenhouse gases relative to CO_2. Global Warming can lead to Malaria, coastal area damage, agricultural effects, forest damage, plant and animal effects. It is one of the biggest environmental issues that are being dealt with. Table 3 shows the global warming potential assessment of the building.

Table 3 Pharmaceutical Building Global warming potential Assessment

Life Cycle Stage	***Process***	***Global Warming Potential***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	kg CO2 eq	9.77E+05	2.44E+06	2.56E+06	1.62E+06	5.63E+05	8.16E+06
	Transportation	kg CO2 eq	2.90E+04	4.75E+04	7.44E+04	4.79E+04	1.28E+04	2.12E+05
	Total	kg CO2 eq	1.01E+06	2.49E+06	2.64E+06	1.67E+06	5.76E+05	8.38E+06
Construction	Material	kg CO2 eq	2.62E+04	3.93E+04	1.10E+05	2.51E+01	1.96E+04	1.96E+05
	Transportation	kg CO2 eq	4.35E+04	8.21E+04	1.01E+05	4.83E+04	2.25E+04	2.98E+05
	Total	kg CO2 eq	6.97E+04	1.21E+05	2.12E+05	4.83E+04	4.22E+04	4.93E+05
Maintenance	Material	kg CO2 eq	0.00E+00	1.07E+06	0.00E+00	0.00E+00	7.61E+04	1.14E+06
	Transportation	kg CO2 eq	0.00E+00	6.43E+04	0.00E+00	0.00E+00	2.40E+03	6.67E+04
	Total	kg CO2 eq	0.00E+00	1.13E+06	0.00E+00	0.00E+00	7.85E+04	1.21E+06
End-of-Life	Material	kg CO2 eq	2.56E+04	2.25E+04	6.20E+04	3.50E+04	1.05E+04	1.56E+05
	Transportation	kg CO2 eq	2.15E+04	2.28E+04	5.00E+04	2.20E+04	8.93E+03	1.25E+05
	Total	kg CO2 eq	4.71E+04	4.53E+04	1.12E+05	5.70E+04	1.94E+04	2.81E+05
Total Life Cycle			1.12E+06	3.79E+06	2.96E+06	1.77E+06	7.16E+05	1.04E+07

Based on the results, walls increase the potential for global warming more than other assemblies. Figure 8 shows the percentage of each assembly's contribution to the global warming.

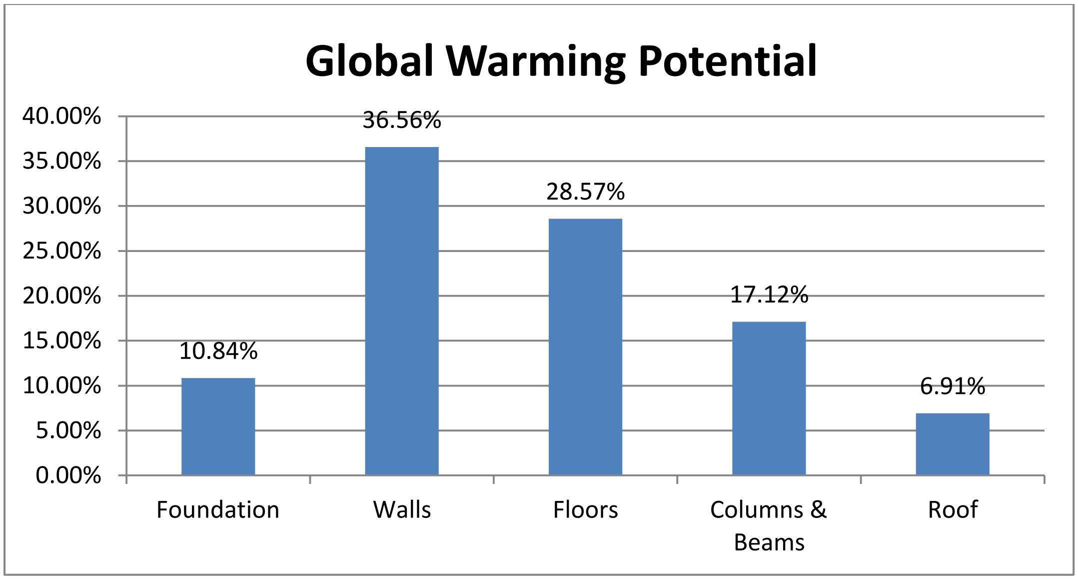

Figure 8. Percentage of each assembly's contribution to Global Warming Potential

4.2.2 Ozone Layer Depletion

Ozone layer depletion is the reduction of the Ozone protective layer which is caused by emissions of substances such as chlorofluorocarbons CFCs) and halons. Reduction in Ozone layer will increase UVB radiation which can cause Skin cancer, cataracts, material damage, immune system suppression, crop damage, other plant and animal effects. This category is measured in terms of mass equivalence of CFC-11. Table 4 shows the Ozone layer depletion assessment of the building.

Table 4 Pharmaceutical Ozone Layer Depletion Assessment

Life Cycle Stage	*Process*	*Ozone Layer Depletion*	*Assembly Group*					*Building Total*
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	kg CFC-11 eq	1.98E-03	4.68E-03	4.58E-03	1.78E-03	8.08E-04	1.38E-02
	Transportation	kg CFC-11 eq	1.22E-06	2.00E-06	3.12E-06	1.99E-06	5.39E-07	8.87E-06
	Total	kg CFC-11 eq	1.98E-03	4.68E-03	4.59E-03	1.78E-03	8.09E-04	1.38E-02
Construction	Material	kg CFC-11 eq	0.00E+00	1.73E-09	0.00E+00	1.14E-11	0.00E+00	1.74E-09
	Transportation	kg CFC-11 eq	1.78E-06	3.37E-06	4.15E-06	1.99E-06	9.23E-07	1.22E-05
	Total	kg CFC-11 eq	1.78E-06	3.37E-06	4.15E-06	1.99E-06	9.23E-07	1.22E-05
Maintenance	Material	kg CFC-11 eq	0.00E+00	1.28E-03	0.00E+00	0.00E+00	5.07E-07	1.28E-03
	Transportation	kg CFC-11 eq	0.00E+00	2.64E-06	0.00E+00	0.00E+00	9.83E-08	2.74E-06
	Total	kg CFC-11 eq	0.00E+00	1.28E-03	0.00E+00	0.00E+00	6.05E-07	1.28E-03
End-of-Life	Material	kg CFC-11 eq	1.15E-06	1.01E-06	2.79E-06	1.58E-06	4.72E-07	7.01E-06
	Transportation	kg CFC-11 eq	8.81E-07	9.35E-07	2.05E-06	9.02E-07	3.66E-07	5.13E-06
	Total	kg CFC-11 eq	2.03E-06	1.95E-06	4.84E-06	2.48E-06	8.38E-07	1.21E-05
Total Life Cycle			1.98E-03	5.96E-03	4.60E-03	1.79E-03	8.11E-04	1.51E-02

Based on the results, Walls increase the potential for Ozone layer depletion more than other assemblies. Figure 9 shows the percentage of each assembly's contribution to the Ozone layer depletion.

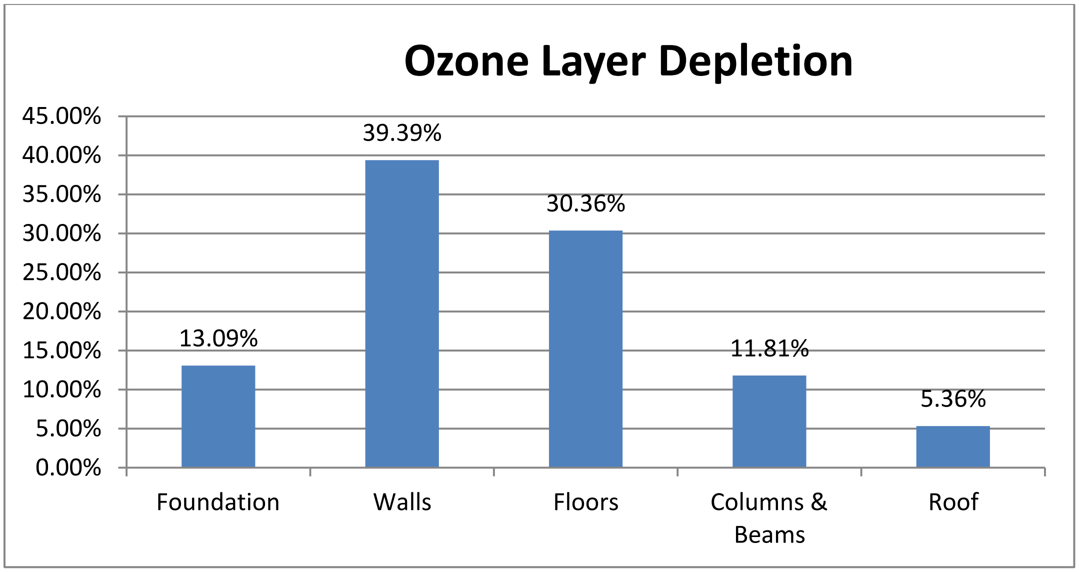

Figure 9 Percentage of each assembly's contribution to Ozone Layer Depletion

4.2.3 Acidification Potential

Acidification occurs when an increase in acidity of water and soil system occurs. Acid deposition has corrosive effect on buildings monuments and historical artifacts. It also can have effects on Plant, animal, and ecosystem effects Acidification is usually occurs due to high amount of SO_2 and NO_X. This category is usually expressed in H_ mole equivalent deposition per kilogram of emission. Table 5 shows the Acidification Potential assessment of the building.

Table 5 Pharmaceutical Building Acidification Potential Assessment

Life Cycle Stage	***Process***	***Acidification Potential***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	moles of H+ eq	3.34E+05	1.24E+06	8.68E+05	5.58E+05	1.83E+05	3.18E+06
	Transportation	moles of H+ eq	1.23E+04	2.04E+04	3.09E+04	1.82E+04	5.34E+03	8.71E+04
	Total	moles of H+ eq	3.46E+05	1.26E+06	8.99E+05	5.76E+05	1.88E+05	3.27E+06
Construction	Material	moles of H+ eq	1.36E+04	2.05E+04	5.00E+04	1.36E+01	8.86E+03	9.29E+04
	Transportation	moles of H+ eq	1.38E+04	2.85E+04	3.26E+04	1.86E+04	7.12E+03	1.01E+05
	Total	moles of H+ eq	2.74E+04	4.90E+04	8.26E+04	1.86E+04	1.60E+04	1.94E+05
Maintenance	Material	moles of H+ eq	0.00E+00	5.47E+05	0.00E+00	0.00E+00	4.45E+04	5.91E+05
	Transportation	moles of H+ eq	0.00E+00	2.13E+04	0.00E+00	0.00E+00	7.72E+02	2.21E+04
	Total	moles of H+ eq	0.00E+00	5.68E+05	0.00E+00	0.00E+00	4.53E+04	6.13E+05
End-of-Life	Material	moles of H+ eq	1.42E+03	1.25E+03	3.44E+03	1.94E+03	5.81E+02	8.62E+03
	Transportation	moles of H+ eq	6.78E+03	7.20E+03	1.58E+04	6.95E+03	2.82E+03	3.95E+04
	Total	moles of H+ eq	8.20E+03	8.45E+03	1.92E+04	8.89E+03	3.40E+03	4.81E+04
Total Life Cycle			3.82E+05	1.89E+06	1.00E+06	6.03E+05	2.53E+05	4.12E+06

Same as the previous impact categories, walls have the most significant effect on Acidification Potential. Figure 10 shows the percentage of each assembly's contribution to this impact category.

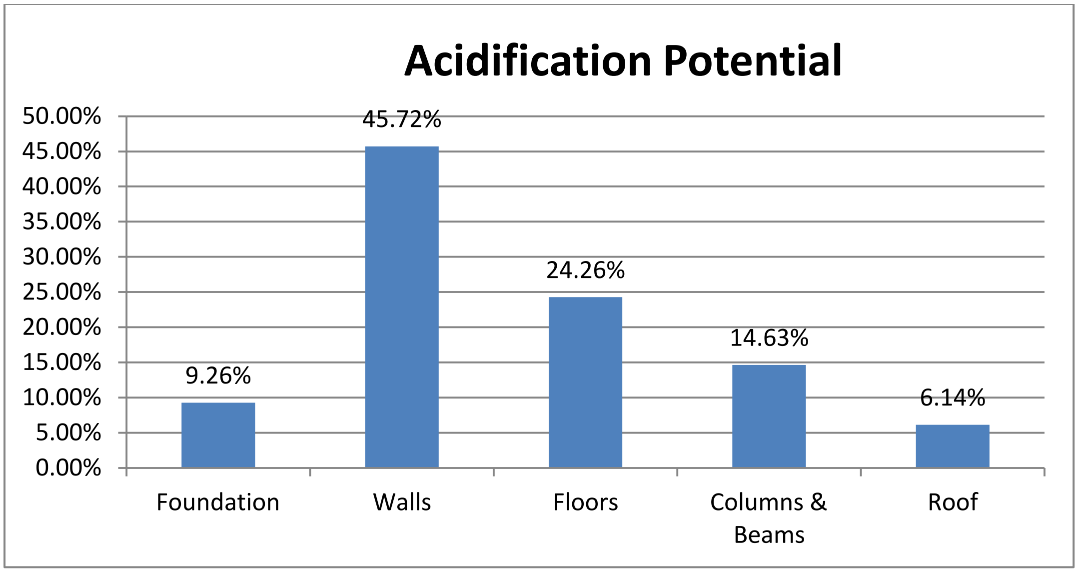

Figure 10 Percentage of each assembly's contribution to Acidification Potential

4.2.4 Eutrophication Potential

When water receives excessive nutrients, it leads to dense growth of plant life. The decomposition of plants depletes the supply of oxygen which leads to foul odor or taste, death or poisoning of fish[7] and human health impact. This impact category is characterized by equivalent mass of nitrogen basis. Table 6 shows the eutrophication potential assessment of the building.

Table 6. Pharmaceutical Building Eutrophication Potential Assessment

Life Cycle Stage	*Process*	*Eutrophication Potential*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
Manufacturing	Material	kg N eq	244.78	806.61	1,204.20	1,956.53	201.17	4,413.30
	Transportation	kg N eq	12.97	21.50	32.57	19.02	5.62	91.67
	Total	kg N eq	257.76	828.11	1,236.77	1,975.55	206.79	4,504.97
Construction	Material	kg N eq	11.82	19.15	50.06	0.01	8.88	89.91

[7] http://wordnetweb.princeton.edu/perl/webwn?s=eutrophication

Life Cycle Stage	***Process***	***Eutrophication Potential***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
	Transportation	kg N eq	14.32	29.75	33.82	19.49	7.38	104.75
	Total	kg N eq	26.14	48.89	83.88	19.50	16.25	194.66
Maintenance	Material	kg N eq	0.00	374.84	0.00	0.00	16.45	391.29
	Transportation	kg N eq	0.00	22.17	0.00	0.00	0.80	22.98
	Total	kg N eq	0.00	397.02	0.00	0.00	17.25	414.26
End-of-Life	Material	kg N eq	0.97	0.86	2.36	1.33	0.40	5.92
	Transportation	kg N eq	6.41	6.80	14.89	6.56	2.66	37.33
	Total	kg N eq	7.38	7.66	17.25	7.90	3.06	43.25
Total Life Cycle			2.91E+02	1.28E+03	1.34E+03	2.00E+03	2.43E+02	5.16E+03

Columns and beams have the major contribution to this impact category. Columns and beams majorly consist of concrete and rebar looking at BOM it can be seen that the amount of rebar in this building assembly is more than other assemblies. Therefore, they high effect of walls on eutrophication potential might be due to high amount of rebar being used in this assembly. Figure 11 shows the percentage of each assembly’s contribution to this impact category.

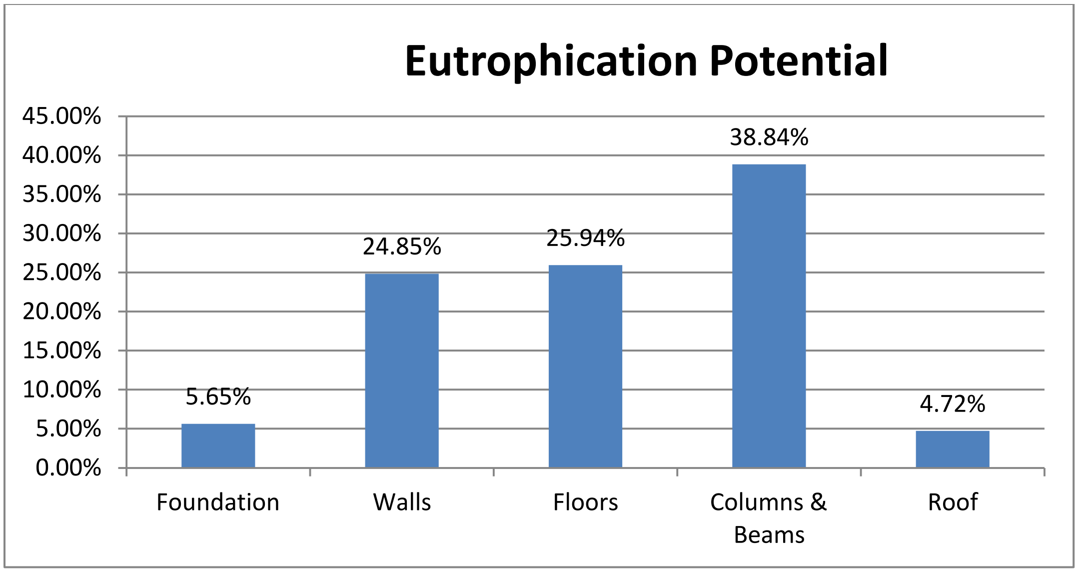

Figure 11 Percentage of each assembly's contribution to Eutrophication Potential

4.2.5 Smog Potential

Smog is a kind of pollution majorly resulting from vehicular emissions and industrial fumes. These emissions can react with the sunlight and form photochemical smog as well. Smog can lead to Human mortality, asthma effects, and plant effects. Smog potential will basically express as NO_X Equivalent. Table 7 shows the smog potential assessment of the building.

Table 7 Pharmaceutical Building Smog Potential Assessment

Life Cycle Stage	*Process*	*Smog Potential*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
Manufacturing	Material	kg NOx eq	4,940.72	10,025.87	11,920.34	5,697.83	2,679.78	35,264.54
	Transportation	kg NOx eq	284.45	471.50	713.33	414.44	122.97	2,006.68
	Total	kg NOx eq	5,225.16	10,497.37	12,633.67	6,112.27	2,802.75	37,271.22
Construction	Material	kg NOx eq	310.41	475.89	1,248.35	0.14	221.42	2,256.21
	Transportation	kg NOx eq	308.62	643.10	729.17	422.76	158.94	2,262.59
	Total	kg NOx eq	619.03	1,118.99	1,977.52	422.91	380.36	4,518.81
Maintenance	Material	kg NOx eq	0.00	5,882.20	0.00	0.00	747.69	6,629.89
	Transportation	kg NOx eq	0.00	478.98	0.00	0.00	17.28	496.26
	Total	kg NOx eq	0.00	6,361.18	0.00	0.00	764.97	7,126.15
End-of-Life	Material	kg NOx eq	18.22	16.04	44.16	24.94	7.47	110.82

Life Cycle Stage	Process	Smog Potential	Assembly Group					Building Total
			Foundation	Walls	Floors	Columns & Beams	Roof	
	Transportation	kg NOx eq	151.35	160.74	351.80	155.07	62.85	881.82
	Total	kg NOx eq	169.57	176.78	395.96	180.01	70.32	992.63
Total Life Cycle			6.01E+03	1.82E+04	1.50E+04	6.72E+03	4.02E+03	4.99E+04

Same as the other impact categories, walls have the most effective impact in smog potential. Figure 5 shows the percentage of each assembly's contribution to this impact category.

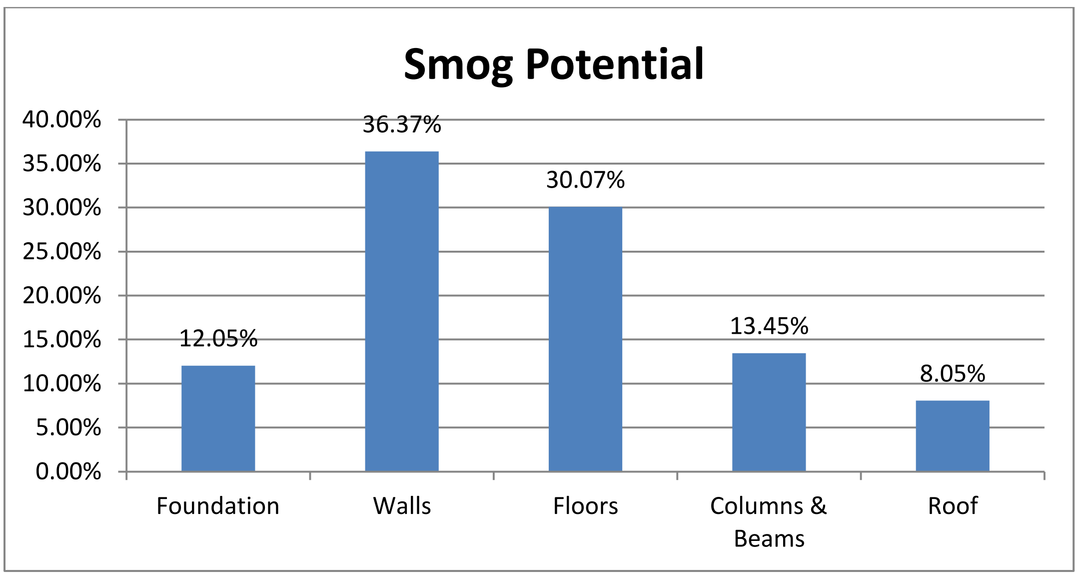

Figure 12 Percentage of each assembly's contribution to Smog Potential

4.2.6 Human Health Respiratory Effects

Human Health Respiratory Effects mainly focuses on the effect of particular matters (PM) on human's respiratory system health. This impact category is expressed through equivalent particular matter size ($PM_{2.5}$) Basis. Table 8 shows the Human Health Respiratory Effects assessment of the building.

Table 8. Pharmaceutical Building Human Health Respiratory Effects Assessment

Life Cycle Stage	Process	Human Health Respiratory Effects	Assembly Group					Building Total
			Foundation	Walls	Floors	Columns & Beams	Roof	
Manufacturing	Material	kg PM2.5 eq	2,275.93	14,618.78	5,629.69	3,108.77	1,080.44	26,713.61
	Transportation	kg PM2.5 eq	14.96	24.78	37.57	21.97	6.48	105.76
	Total	kg PM2.5 eq	2,290.89	14,643.56	5,667.26	3,130.75	1,086.91	26,819.37
Construction	Material	kg PM2.5 eq	13.39	22.85	56.72	0.01	10.06	103.04
	Transportation	kg PM2.5 eq	16.61	34.43	39.21	22.51	8.56	121.33
	Total	kg PM2.5 eq	30.00	57.28	95.94	22.53	18.61	224.36
Maintenance	Material	kg PM2.5 eq	0.00	14,133.01	0.00	0.00	167.85	14,300.86
	Transportation	kg PM2.5 eq	0.00	25.69	0.00	0.00	0.93	26.62
	Total	kg PM2.5 eq	0.00	14,158.71	0.00	0.00	168.78	14,327.49
End-of-Life	Material	kg PM2.5 eq	1.35	1.19	3.27	1.85	0.55	8.21
	Transportation	kg PM2.5 eq	8.15	8.66	18.94	8.35	3.38	47.48
	Total	kg PM2.5 eq	9.50	9.84	22.21	10.20	3.94	55.69
Total Life Cycle			2.33E+03	2.89E+04	5.79E+03	3.16E+03	1.28E+03	4.14E+04

Walls still have the most significant effect on this impact. Figure 13 shows the percentage of each assembly's contribution to this impact category.

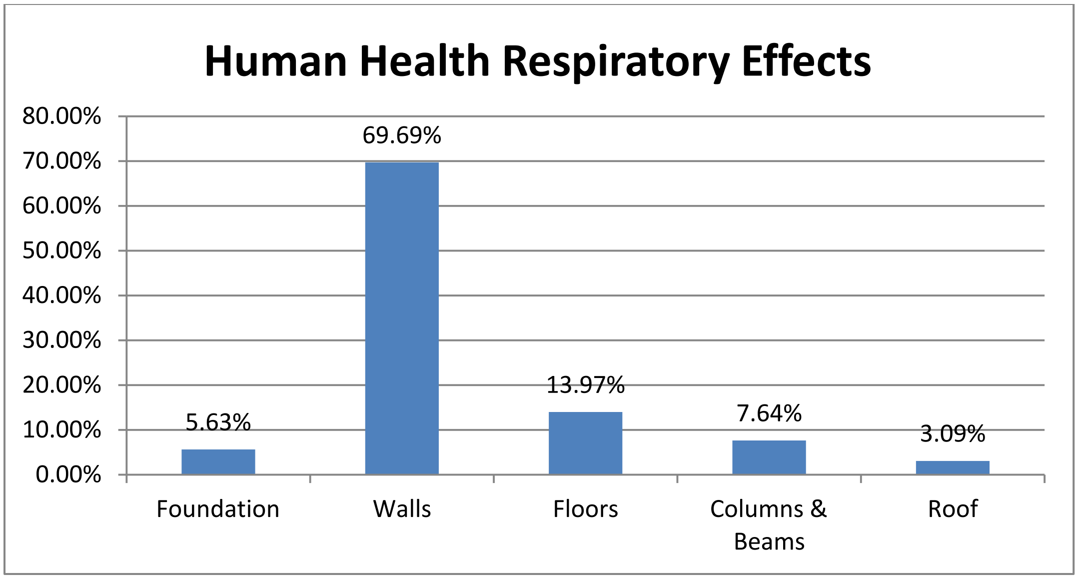

Figure 13 Percentage of each assembly's contribution to Human Health Respiratory Effects

4.2.7 Weighted Resource Use

Weighted Resource Use relates to the resources that used to manufacture building materials. It is reported as Kg. Table 9 shows the Weighted Resource Use assessment of the building.

Table 9 Pharmaceutical Building Weighted Resource Use Assessment

Life Cycle Stage	*Process*	*Weighted Resource Use*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
Manufacturing	Material	ecologically weighted kg	9.39E+06	8.86E+06	2.20E+07	1.00E+07	3.84E+06	5.42E+07
	Transportation	ecologically weighted kg	1.20E+04	2.14E+04	3.02E+04	1.78E+04	5.20E+03	8.65E+04
	Total	ecologically weighted kg	9.41E+06	8.88E+06	2.21E+07	1.01E+07	3.84E+06	5.42E+07
Construction	Material	ecologically weighted kg	8.99E+03	1.23E+04	3.78E+04	1.74E+00	6.72E+03	6.58E+04
	Transportation	ecologically weighted kg	1.38E+04	2.90E+04	3.27E+04	1.92E+04	7.11E+03	1.02E+05

Life Cycle Stage	*Process*	*Weighted Resource Use*	*Assembly Group*					*Building Total*
			Foundation	*Walls*	*Floors*	*Columns & Beams*	*Roof*	
	Total	ecologically weighted kg	2.28E+04	4.13E+04	7.05E+04	1.92E+04	1.38E+04	1.68E+05
Maintenance	Material	ecologically weighted kg	0.00E+00	1.35E+06	0.00E+00	0.00E+00	1.16E+05	1.47E+06
	Transportation	ecologically weighted kg	0.00E+00	2.13E+04	0.00E+00	0.00E+00	7.74E+02	2.21E+04
	Total	ecologically weighted kg	0.00E+00	1.37E+06	0.00E+00	0.00E+00	1.17E+05	1.49E+06
End-of-Life	Material	ecologically weighted kg	9.24E+03	8.13E+03	2.24E+04	1.26E+04	3.79E+03	5.62E+04
	Transportation	ecologically weighted kg	6.77E+03	7.19E+03	1.57E+04	6.93E+03	2.81E+03	3.94E+04
	Total	ecologically weighted kg	1.60E+04	1.53E+04	3.81E+04	1.96E+04	6.60E+03	9.56E+04
Total Life Cycle			9.45E+06	1.03E+07	2.22E+07	1.01E+07	3.98E+06	5.60E+07

Floors have the most impact on this impact category and play the main role. Figure 14 shows the percentage of each assembly's contribution to this impact category.

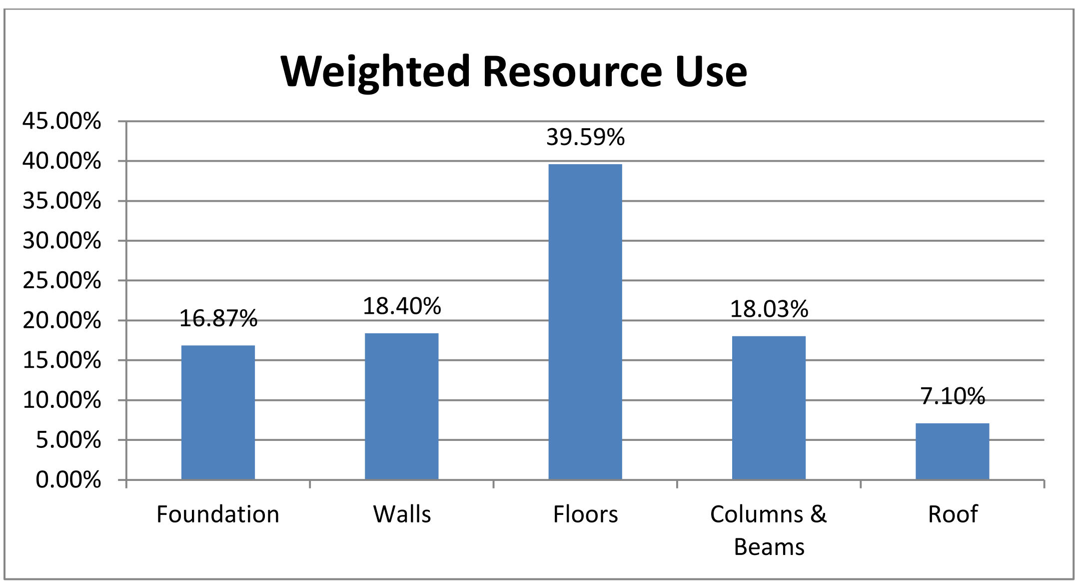

Figure 14 Percentage of each assembly's contribution to Weighted Resource Use

4.2.8 Fossil Fuel Use

Fossil fuel use is related to the energy use for manufacturing, transportation, construction and demolition of the materials during the life cycle of the building. It is shown as Mega Joules (MJ). Its shortage might lead to use of other sources of energy which may cause different environmental impacts. Table 10 shows the Fossil Fuel Use assessment of the building.

Table 10 Pharmaceutical Building Fossil Fuel Use Assessment

Life Cycle Stage	***Process***	***Fossil Fuel Use***	***Assembly Group***					***Building Total***
			Foundation	***Walls***	***Floors***	***Columns & Beams***	***Roof***	
Manufacturing	Material	MJ	5,984,184.11	23,374,055.46	21,406,743.65	25,722,870.53	6,253,977.74	82,741,831.48
	Transportation	MJ	511,130.76	913,766.29	1,286,736.34	758,090.58	221,684.03	3,691,408.00
	Total	MJ	6,495,314.87	24,287,821.74	22,693,479.98	26,480,961.11	6,475,661.77	86,433,239.48
Construction	Material	MJ	387,907.80	530,775.92	1,630,551.95	71.10	289,937.83	2,839,244.60
	Transportation	MJ	586,085.38	1,231,960.92	1,386,509.39	816,911.93	301,662.11	4,323,129.73
	Total	MJ	973,993.18	1,762,736.84	3,017,061.34	816,983.03	591,599.94	7,162,374.33
Maintenance	Material	MJ	0.00	4,825,336.59	0.00	0.00	4,405,228.92	9,230,565.51
	Transportation	MJ	0.00	905,944.29	0.00	0.00	32,856.06	938,800.35
	Total	MJ	0.00	5,731,280.88	0.00	0.00	4,438,084.98	10,169,365.86
End-of-Life	Material	MJ	392,245.60	345,318.66	950,758.04	536,983.54	160,808.26	2,386,114.09
	Transportation	MJ	287,220.82	305,040.50	667,616.13	294,283.63	119,267.89	1,673,428.96
	Total	MJ	679,466.41	650,359.16	1,618,374.17	831,267.16	280,076.15	4,059,543.05
Total Life Cycle			8.15E+06	3.24E+07	2.73E+07	2.81E+07	1.18E+07	1.08E+08

From the table above, it can be seen that like other impact categories walls, columns and beams, and floors cause almost the same proportion of fossil fuel use. Figure 15 shows the percentage of each assembly's contribution to this impact category.

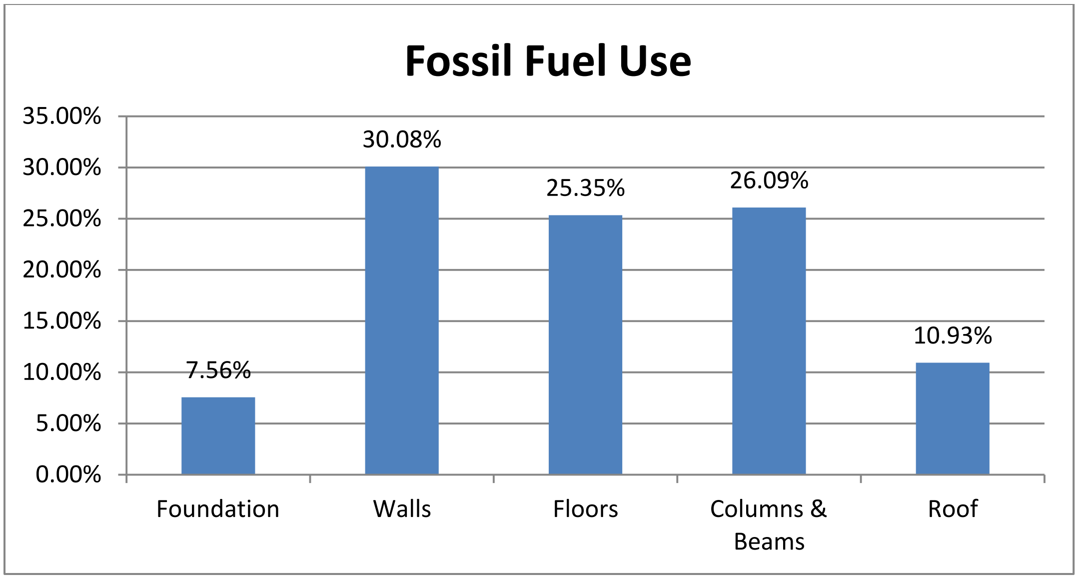

Figure 15 Percentage of each assembly's contribution to Fossil fuel use

4.3 Uncertainty

Considering LCA as a decision tool, it is important to know to which extent the outcomes are reliable. As LCA involves data gatherings, assumptions and simplifications, there will be uncertainties in different aspects of the study. LCA is usually being used at the design phase of the project to help the decision maker come up with the decisions that are more environmental friendly. In this phase of the project, lots of uncertainties exist due to conceptual design of the building. Knowing these uncertainties can help the decision maker to process outcomes of LCA instead of working with the mere outcomes.

Uncertainties exist in the 3 fundamental parts of the analysis, goal and scope, Inventory analysis, and impact assessment. For instance, a system boundary is assumed for this study. In this phase we disregarded the phases before site preparation and demolishing the previous building; however, demolishing can significantly affect the environmental impacts. An assumption was made for the service life of the project, however, there is a great uncertainty regarding maintenance of the building. Even the maintenance cycle involves some uncertainties.

In the data collection phase, doing the quantity take off involves some uncertainties. For instance using the On Screen take off software and extracting data from the 2D files is not completely accurate. In Addition, there were some missing data that some assumptions had to be made for that. These can bring up some uncertainties in this phase of the project.

Having these inputs, IE will come up with some results that contain some uncertainties. For instance, Column and Beam sizes are designed by IE based on some rough information provided as input to IE. Looking at the BOM and impact category results in previous sections, it is clear that IE calculates the environmental impacts from BOM which creates; however, there is a great uncertainty about that. There is a possibility that the software over designed the structural elements which makes the decision maker hesitant about the reliability of the outcomes.

In addition, as IE has a limited list of materials, when the exact material didn't exist in IE the closest option to that material was chosen. However, these two materials may completely have different environmental impacts.

There are other uncertainties regarding the location of the building, climate, regional differences in environmental sensitivity, IE data base, IE assumptions, interpretation of impacts over time, mistakes, etc.

4.4 Sensitivity Analysis

Sensitivity Analysis can help the decision maker understand changing the amount of which materials in the building have the most effective impact on the environment. By knowing the materials to which impact categories are most sensitive, the decision maker can focus on those materials more, rather than focusing on the whole building. It can help the decision maker to study those materials in greater details and try to reduce the environmental impacts of it. The decision maker can reduce the environmental impact of that material by changing the material to a more environmental friendly material. Changing the transportation mode or the supplier to reduce the environmental impact of transportation can help as well. In some cases, even changing one raw material in the product can cause a significant reduction in negative environmental impacts.

For Pharmaceutical building five different materials were selected and their amounts were increased by 10% in order to study if the impact categories are sensitive to these changes. It was tried to choose the materials that is thought are used the most in the building. These materials are Concrete 30 MPa (flyash avg), Rebar, Rod, Light Sections, Glazing Panel, Galvanized stud, and 5/8" Fire-Rated Type X Gypsum Board. Figure 16 to Figure 20 shows the sensitivity of each impact categories to 10% increase in each of the materials.

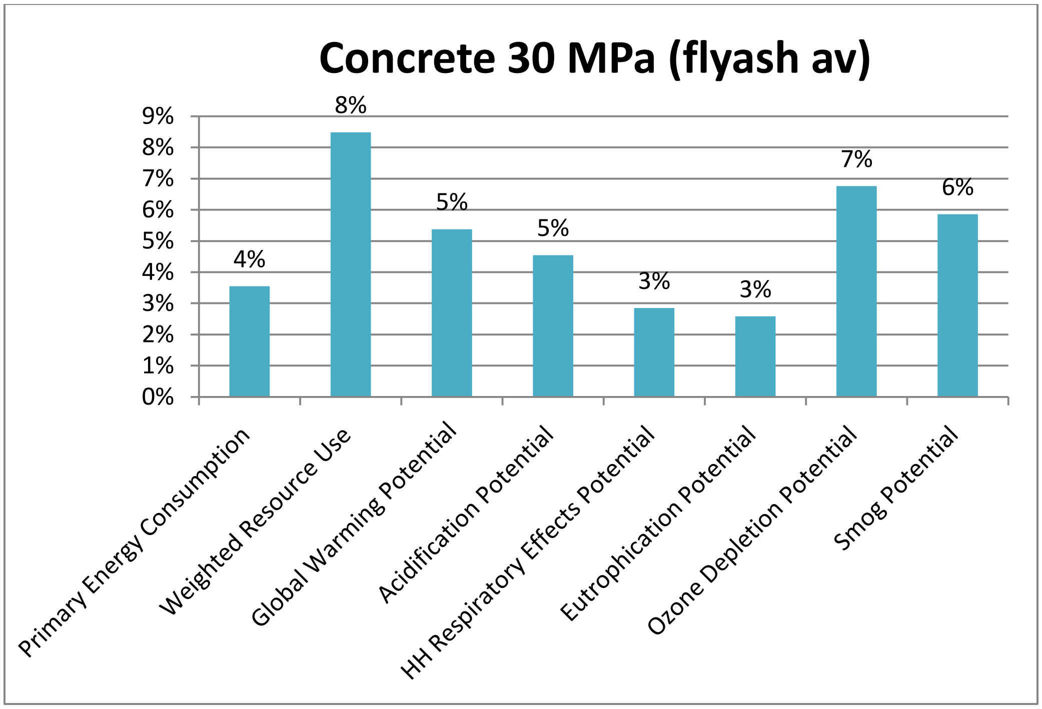

Figure 16 the sensitivity of each impact categories to 10% increase in Concrete 30 MPa (flyash av)

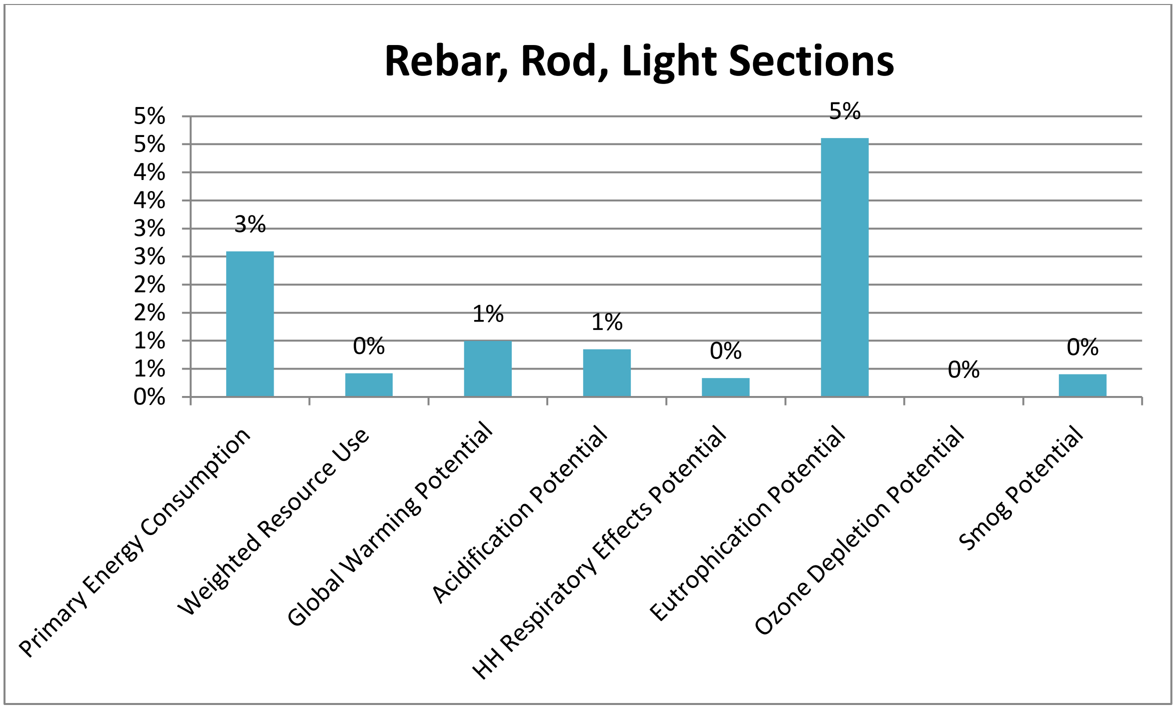

Figure 17 the sensitivity of each impact categories to 10% increase in Rebar, Rod, and Light Sections

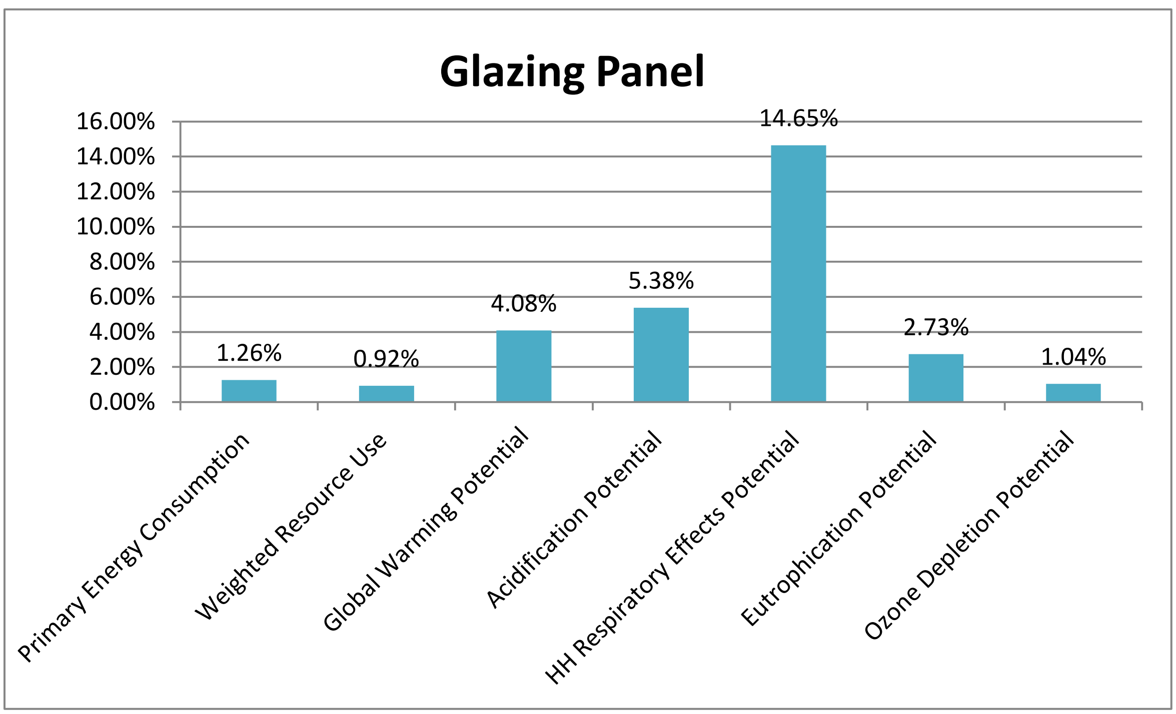

Figure 18 the sensitivity of each impact categories to 10% increase in Glazing Panel

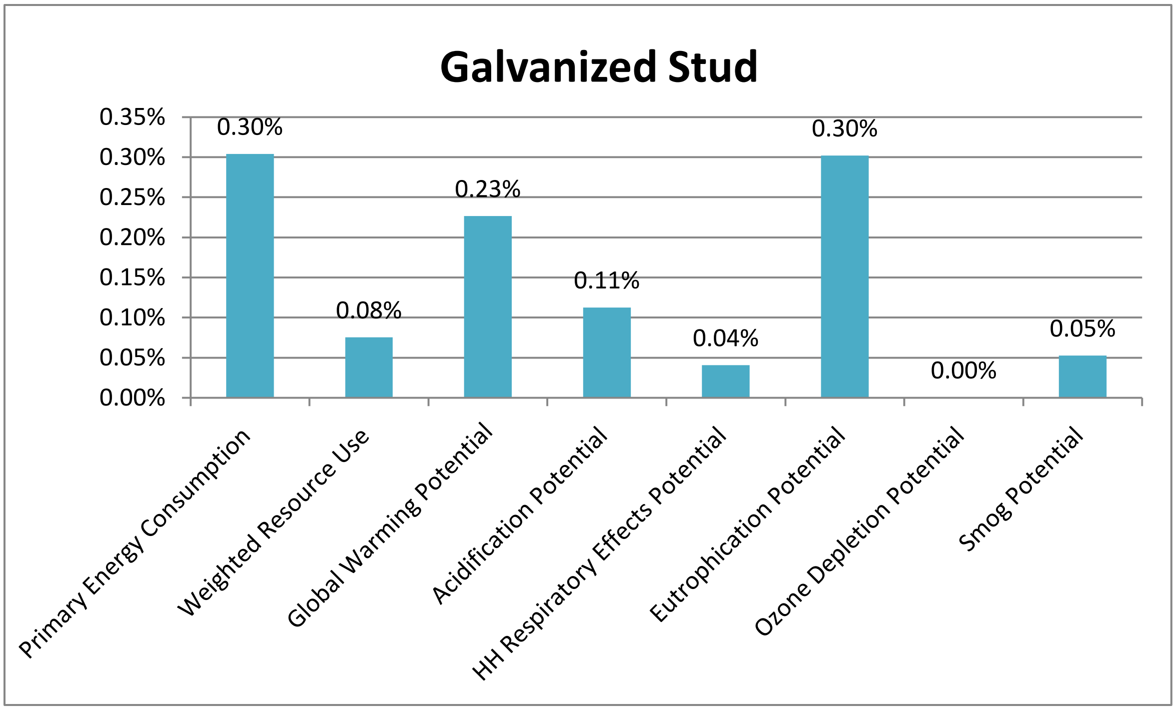

Figure 19 the sensitivity of each impact categories to 10% increase in Galvanized Stud

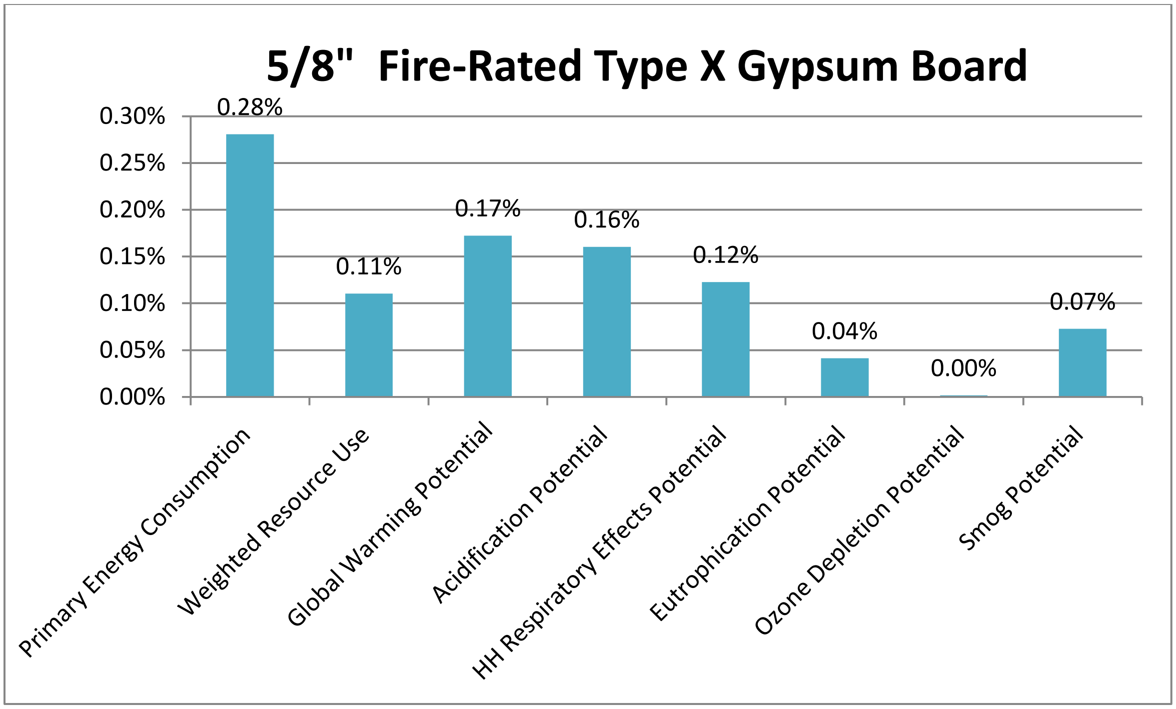

Figure 20 the sensitivity of each impact categories to 10% increase in 5/8" Fire-Rated Type X Gypsum Board

Based on the sensitivity analysis, Concrete 30 MPa (flyash av), Rebar, Rod, Light Sections, and glazing Panel are the materials that needs paying attention as the 10% increase in their quantity makes noticeable differences in most of the impact categories.

In addition, if one specific impact category is the focus, the decision maker can decide on the material that he should focus on, by looking at the sensitivity analysis. For instance, if the purpose is decreasing HH Respitory Effects Potential, glazing panel is the material that he needs to study more in detail.

As a result, in order to reduce the environmental impacts of the building, these three materials are among the materials that the decision maker should focus on. For instance, he can try to substitute concrete with another material that works or changing the envelope or a part of it to another material can also help. If the decision maker can trace back the materials, there is a possibility that by providing them from another source the transportation impacts can be reduced. Using more durable material can also help since it affects the maintenance stage of the project.

It is also observed that the impact categories are not sensitive to Galvanized stud, and 5/8" Fire-Rated Type X Gypsum Board. Therefore, changing them cannot be helpful to the environment.

4.5 Chain of Custody

Among the materials that are highly being used in the building and the environmental impact categories are sensitive to them, curtain panel system was selected for the chain of custody. In this section the materials used in the product should be traced back to the manufacturer and to the raw material extraction. For this purpose, the construction manager of the project (Ledcor Co.) was contacted via phone call. After explaining the purpose of the study, the company gave the site's phone number. Calling to the site, they asked for an email to be written to them requesting the information about manufacturer. Waiting for a reply, one of the authors went to the site and asked for the manufacturer personally. Intricate Glass Co. name was given as the manufacturer. Trying to contact to intricate glass, they made it clear that the company just installed the curtain system which was provided by manufacturer. Sending an follow up email, they gave the information of the manufacturer which was Inland Glass & Aluminum Co.. After calling the company it took a day to get the required information; however, some parts were missing. The company's project manager declared that tracing back all the materials that is being used for manufacturing is a complicated time consuming process; therefore, just the main components i.e. glass and aluminum extrusion's data were provided.

According to the project manager, for aluminum extrusion the materials are extracted in Ferndale Washington and manufactured in Portland Oregon. Glass is manufactured in Minnesota and there is no data on where the raw materials were produced. Then the extrusions and glass come to company's shop in Kamloops and then are shipped to the site. All the transportations are by truck.

Looking at the process to trace back the materials, it is a time consuming process. For curtain walls it took about three to four business days to find these information which is not detailed and complete. Looking at the BOM with 33 different materials, tracing back all these materials seems to be time consuming energy taking process. If all of these materials are going to be traced back one at a time, in ideal situation it will take 132 business days to trace them all back and still it is not that much detailed and complete.

4.6 Building Functions

The building is intended to be Faculty of Pharmaceutical sciences and center for drug research and development which includes teaching, learning, research and community outreach activities. Therefore, different functional area types are defined for that such as classrooms, research labs, offices and etc., Table 11 shows the different functional area types, their assigned gross floor area, and their percentage of total area buildings. It shows that near half of the building is assigned to offices and Study/Research/Prep/Computer lab rooms.

Table 11. Building Functions

Functional Area Type	*Gross Floor Area (ft2)*	*Percentage of Total Building Area*
Classrooms	2,460.59	10.76%
Offices/Office Spaces	5,493.90	24.02%
Testing labs	2,030.38	8.88%
Library	287.18	1.26%
Study/Research/Prep/Computer lab rooms	6,170.61	26.98%
Storage rooms	38.15	0.17%
Stairwells/Halls/ Atriums	2,913.69	12.74%
Washrooms/ Locker rooms	498.50	2.18%
Mechanical rooms	2,225.00	9.73%
Auditorium/ Lecture Halls	753.00	3.29%
Building Total	22,871	

4.7 Functional Unit

Functional unit is a key element in LCA and needs to be clearly defined. It describes and quantifies those properties of the product, which must be present for the studied substitution to take place (Weidema et al. 2004). The main porpose of the functional unit is to have a reference unit to which all the inputs and outputs are referred. It helps to make comparisons between the results of different studies.8

For this study, four different functional units were introduced. The functional units are defined in a way that is believed can present the outputs of study in a clear way and makes it easy to compare with other academic buildings. Each functional unit is defined and the results are shown as follows:

[8] http://www.stonecourses.net/environment/goallca.html

4.7.1 Per generic post-secondary academic building square meter constructed

The building total impact results are divided by the gross floor area and the results are shown in Table 12. This functional unit gives the readers an idea that every square meter of an academic building has these environmental impacts.

Table 12 Impact category results based on per generic post-secondary academic building square meter constructed

Impact Category	*Results*	*Functional Unit*
		per generic post-secondary academic building square meter constructed
Fossil Fuel Consumption MJ	107,824,522.73	4,714.46
Weighted Resource Use kg	55,997,007.97	2,448.38
Global Warming Potential (kg CO2 eq)	10,360,296.65	452.99
Acidification Potential (moles of H+ eq)	4,124,439.69	180.33
HH Respiratory Effects Potential (kg PM2.5 eq)	41,426.92	1.81
Eutrophication Potential (kg N eq)	5,157.14	0.23
Ozone Depletion Potential (kg CFC-11 eq)	0.02	0.00
Smog Potential (kg NOx eq)	49,908.81	2.18

4.7.2 Per specific post-secondary academic building square meter constructed

For this functional unit the total building results are propagated between different functional area types of the building considering their area percentage of the whole building. There is a designated functional unit for every impact category and the proportion of this impact category is defined by the functional unit. Table 13 shows the results for this functional unit.

Table 13 Functional unit per specific post-secondary academic building square meter constructed

	Functional unit per specific post-secondary academic building square meter constructed							
Functional area type	***Fossil Fuel Consumption MJ***	***Weighted Resource Use kg***	***Global Warming Potential (kg CO2 eq)***	***Acidification Potential (moles of H+ eq)***	***HH Respiratory Effects Potential (kg PM2.5 eq)***	***Eutrophication Potential (kg N eq)***	***Ozone Depletion Potential (kg CFC-11 eq)***	***Smog Potential (kg NOx eq)***
Classrooms	507.208	263.411	48.735	19.401	0.195	0.024	7.122E-08	0.235
Offices/Office Spaces	1,132.473	588.133	108.813	43.319	0.435	0.054	1.59E-07	0.524
Testing labs	418.528	217.356	40.214	16.009	0.161	0.020	5.877E-08	0.194
Library	59.197	30.743	5.688	2.264	0.023	0.003	8.312E-09	0.027
Study/Research/ Prep/ Computer lab rooms	1,271.966	660.576	122.217	48.654	0.489	0.061	1.786E-07	0.589
Storage rooms	7.864	4.084	0.756	0.301	0.003	0.000	1.104E-09	0.004
Stairwells/Halls/ Atriums	600.607	311.916	57.709	22.974	0.231	0.029	8.434E-08	0.278
Washrooms/ Locker rooms	102.757	53.365	9.873	3.931	0.039	0.005	1.443E-08	0.048
Mechanical rooms	458.646	238.191	44.069	17.544	0.176	0.022	6.44E-08	0.212
Auditorium/ Lecture Halls	155.218	80.610	14.914	5.937	0.060	0.007	2.18E-08	0.072

4.7.3 Per generic post-secondary academic building cubic meter constructed

The previous mentioned functional units do not consider the hight of each floor and as a result the height of the building. In order to take this factor into account, the impact category results are shown per generic post-secondary academic building cubic meter constructed. For this functional unit, the impact category results were divided by the volume of the building. In order to obtain building's volume the average area of the floors is multiplied by the height of the building. Table 14 shows the results for this functional unit.

Table 14 Functional unit- per generic post-secondary academic building cubic meter constructed

Impact Category	*Results*	*Functional Unit*
		per generic post-secondary academic building cubic meter constructed
Fossil Fuel Consumption MJ	107,824,522.73	862.78
Weighted Resource Use kg	55,997,007.97	448.07
Global Warming Potential (kg CO2 eq)	10,360,296.65	82.90
Acidification Potential (moles of H+ eq)	4,124,439.69	33.00
HH Respiratory Effects Potential (kg PM2.5 eq)	41,426.92	0.33
Eutrophication Potential (kg N eq)	5,157.14	0.04
Ozone Depletion Potential (kg CFC-11 eq)	0.02	1.21E-7
Smog Potential (kg NOx eq)	49,908.81	0.40

4.7.4 Per Dollar spent on the investment

This functional unit captures environmental impacts of the building based on the project's investment. If the projects budget is spent in a more conscious manner of the environment, every dollar spent on the project can decrease the environmental impact.

Impact Category	*Results*	*Functional Unit*
		per dollar spent on the investment
Fossil Fuel Consumption MJ	107,824,522.73	6.96E-01
Weighted Resource Use kg	55,997,007.97	3.61E-01
Global Warming Potential (kg CO2 eq)	10,360,296.65	6.68E-02
Acidification Potential (moles of H+ eq)	4,124,439.69	2.66E-02

Impact Category	Results	Functional Unit
		per dollar spent on the investment
HH Respiratory Effects Potential (kg PM2.5 eq)	41,426.92	2.67E-04
Eutrophication Potential (kg N eq)	5,157.14	3.33E-05
Ozone Depletion Potential (kg CFC-11 eq)	0.02	9.77E-11
Smog Potential (kg NOx eq)	49,908.81	3.22E-04

5 Conclusion

The purpose of this study was to do a life cycle assessment of the UBC Faculty of Pharmaceutical Sciences and Center for Drug Research and Development. This building is a new building which is now under construction. The goal and scope of the study is determined for the first step of the study. Quantity take off from foundations, walls, floors, beams and columns, and envelope system was done using the structural and architectural drawings by On Screen Take off software.

In order to model these assembly types in IE, some assumptions and adjustments have been made. All these assumptions are clearly declared so that readers would have a good understanding of the outcomes and help them to utilize them. The Bill of material was extracted from the IE and five materials that are being used the most were chosen for further studies. These five materials are concrete 30Mpa, 5/8" Fire-Rated Type X Gypsum Board, glazing panels, galvanized studs and rebar rod and light sections.

The results from IE which is based on eight impact categories during the manufacturing, construction, maintenance, and end of life phases, were shown and discussed via tables and charts. As the results were shown by different building assemblies, it can be seen which assembly has the main contribution to each impact category. For comparison purposes, four functional units were defined and calculated as well.

A sensitivity analysis was also done for the five materials mentioned before to see the sensitivity of impact categories to 10% increase in these materials. It was concluded that concrete 30MPa, Rebar, Rod, and light section, and glazing panels are the materials that need to be studied in more details to decrease the impact category results in general.

This study did an LCA on Pharmaceutical building; however, the assessment was general. For having results in greater details and accuracy, more building assemblies should be modeled in IE such as flooring and finishing. For decision making purposes, the sensitivity analysis should be done in a more comprehensive way by considering almost all materials that is being used in the building. Therefore, the decision maker has more options to decrease the environmental impacts of the building.

6 References

- Jane C. Bare, 2002, “The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts”, Journal of Industrial Ecology, Volume 6, Issue 3-4, 97-68
- BO Wedema, 2004, “The product, functional unit and reference flows in LCA”, Danish environmental protection Agency, Environmental news, No.70
- http://www.stonecourses.net/environment/goallca.html

7 Authors segment

"Nowadays, **sustainability** is a controversial issue among engineers, environmentalists, and politicians. Individuals are concerned about the environmental impacts of the products they consume, the buildings they live in, and their everyday actions and do everything possible to minimize the environmental impacts of their actions to their highest possible extend. Engineers and environmentalists play an important role in reducing the environmental impacts of new projects, such as new buildings. As an engineer, sustainability and being green is important to me. CIVL 498E course description got my attention and motivated me to learn more about new tools use to implement sustainability practices. Throughout this course, I have learned how to attain quantity takeoffs from On-Screen Takeoff as well as BIM. Also, I have learned how to assess different materials' impacts through using Athena Impact Estimator and performing Sensitivity Analysis.

I have found all these new tools and software useful for future to assess and reduce environmental impacts in designing and construction phases of new projects."

Mahshid Hashemi

“Being involved with Building Information modeling (BIM), I was enthusiastic to see how BIM can Leverage LCA as both areas are evolving in recent years. Going through each step in LCA, I was sure that BIM can help LCA to come up with the results in a faster more accurate manner.

For instance, using On Screen take-off for doing QTO was a time consuming, confusing, error prone task. However, using the 3D model for QTO purposes is a faster more accurate process. In decision making phase, using 3D model can help the decision maker to evaluate his options faster.

One of the most challenging parts in the impact estimator is that the assemblies should be modeled manually in the software. Considering the size of the projects that LCA is usually done for, makes it clear that the inputting phase is a time consuming prone to error process. There is a need to link the 3D model to IE so that the required information flows automatically from the 3D model to IE. In this way different options can be tested in a faster more accurate manner.”

Helia Amiri

Appendix A

Appendix B