UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Life Cycle Assessment and UBC

Eric Ho, Jennifer Law, Jordan Kwun

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Composed by:

- Eric Ho #
- Jordan Kwun #
- Jennifer Law #

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Executive Summary

This document gives an overview of the discussions regarding how LCA can be incorporated into UBC's Building Design and Operations Guidelines, the findings of a LCA study carried out on UBC buildings and how the information can be used in sustainability programs, and the next steps to institutionalizing LCA at UBC.

UBC has numerous actions plans, guidelines and standards which assist consultants in incorporating sustainability to their building design. However, references to LCA are minimal in many of these documents even though it is the only science-based tool to quantitatively support the decision making of building design in terms of its environmental impact and overall sustainability. Recommendations to further incorporate LCA into Climate Action Plan, Vancouver Campus Plan Part 3 Design Guidelines, Technical Guidelines, UBC RFI Evaluation Criteria, and LEED v4 have been made in the report. This will allow LCA to have a bigger presence in UBC building design and operations, resulting in construction of greener, more sustainable infrastructures in the future.

Data were compiled in previous years for Civil 498c by completing quantity takeoffs and LCA studies for individual UBC Buildings, which was then used to improve overall sustainability of buildings on campus. However, this year's class objective uses LCA studies done by previous years to observe how current UBC buildings are impacting the environment and how materials and design components will affect impact categories from each building. The results from this year's projects give a good insight on how easily LEED points can be awarded without substantial reduction in environmental impacts.

The next step to institutionalize LCA is to consider LCA tools, databases and LCIA methods. Suitable programs are researched in order to find suitable ones such as Athena EIE and TRACI. Decision methods and weighting criteria are also considered to meet UBC's Green Building initiative. Recommendations for institutionalizing LCA in UBC are stated in regards to the success factors such as an entrepreneur who pushes LCA initiatives, the involvement of practitioners and development of a formalized structure. Suggestions to educational and communication initiatives are developed while keeping the success factors in mind.

1.0 Introduction

Life Cycle Assessment (LCA) is a method of quantifying the sustainability of a building design. LCA quantifies this based on environmental impact categories that can negatively impact human health as well as the surrounding environment. The contents of this report strive to demonstrate the practicality of LCA as a tool to create and design sustainable new buildings throughout UBC. This will be demonstrated through the context for use of LCA and how it can be applied to existing UBC building and sustainability plans and guidelines. Cradle-to-grave LCA studies of 24 UBC Academic buildings were done and the results and findings will be discussed here. Lastly, how UBC can institutionalize LCA into their building design and operations will be a topic of discussion.

2.0 Context for Use of LCA at UBC

Currently, UBC has numerous documents, actions plans, guidelines and standards to assist consultants in building and incorporating sustainability to the building. However, references to LCA are minimal in many of these documents. LCA is the only science-based and credible tool in the industry to quantitatively support the decision making of building design in terms of its environmental impact and overall sustainability. Moreover, UBC 's ultimate goal is to become a greener and more sustainable campus and this initiative has been reflected in all the documents, action plans, guidelines and standards associated with building design and construction. Therefore, there is a need to incorporate LCA into these design guidelines and institutionalize environmental life cycle assessment (LCA) into UBC building design and operations. This section of the report will look at the Climate Action Plan, Vancouver Campus Plan Part 3 Design Guidelines, Technical Guidelines, UBC RFI Evaluation Criteria, and LEED v4 and look for opportunities to further expand the contents of these documents by incorporating LCA into its design procedures and requirement lists.

2.1 Climate Action Plan

UBC's Climate Action Plan is a report on UBC Building and Operations' current trends in energy consumption and waste production, causing an increase in greenhouse gas emissions (GHG). The report also discusses UBC's commitment to reducing its overall GHG emissions by a certain percentage by a certain year and discusses actions plans which the university will undergo in order to ultimately achieve a zero GHG emission campus.

Upon review of UBC's Climate Action Plan, the use of a Life-Cycle Analysis (LCA) should not be a building design and operations requirement due to the differences in scope considerations. The Climate Action Plan is designed to only address all GHG emissions within the campus (buildings, maintenance fleet vehicles, etc...) The plan mainly considers how a building within UBC grounds will consume energy and produce wastes such that it will increase GHG emissions. However, the system boundary of a building assessed by LCA extends beyond just the GHG emissions within an area. While UBC's Climate Action Plan considers how the building material and operational systems will emit GHG gas, LCA goes beyond this step by considering the GHG emission that is involved during raw material supply, manufacturing, assembly and deliverance as well. Moreover, GHG emission is only one of nine impact categories that LCA will assess when analyzing the inputs and outputs of a building. The remaining impact categories include acidification, human health particulates, eutrophication, ozone depletion, smog potential, total primary energy consumed, non-renewable energy consumed, and fossil fuel consumed. Since UBC is only concerned with GHG impact categories, the information provided during the LCA process may exceed what is necessary and bring about confusion and unnecessary concerns.

Although the use of LCA is not recommended for most cases, the exception to this would be during the UBC "Renew Program," a program that is incorporated into the Climate Action Plan. The Renew Program is the commitment from UBC to renovate old, eligible existing buildings and make them more sustainable and environmentally friendly. Allison Huffman and her team (2010)'s paper, "*The Greenest Building is the One that is Never Built: A Life-Cycle Assessment Study of Embodied Effects for Historic Buildings*," presents the fact that LCA can be used in the renovation and upgrade process of existing buildings while measuring common environmental measures such as global warming. The methodology to compare the benefits of retaining an existing building rather than constructing a new one is available and certainly can be used by UBC for its Renew Program if necessary.

2.2 Vancouver Campus Plan Part 3 Design Guidelines

UBC's Vancouver Campus Plan Part 3 Design Guidelines details design guidelines and regulation standards for renovations and additions done to the buildings and landscape infrastructures of the university. The guidelines state that any renovations and additions should contribute and preserve the heritage aspect of the building and landscape. This includes the building's architecture, colour palettes and landscape. In particular of interest is the material palette. The current market for building materials understand that clients want products that are sustainable and green. However, which material truly achieves the sustainability standards that the client needs and how the product will impact the environment is something that required further investigation.

A recommendation would be to incorporate the use of building materials and products that contain an Environmental Product Declaration (EPD). EPD's are summary documents of products that have undergone the LCA process and have been verified by a third-party to be valid and correct. EPD's offers product transparency in terms of its environmental performances and impacts. Many manufacturers and suppliers of building materials have hired LCA-practicing consultant groups and organizations to perform a life-cycle analysis of their building material products and assess the inputs, outputs and environmental impacts of the product across its lifespan from cradle to grave.

The development process of an EPD follows a set of rules and regulations that are standardized throughout the world. These rules, called the Product Category Rules, are defined in ISO 14025 – Environmental Labels and Declarations – Type III Environmental Declarations. There are different sets of rules for different product categories (group of products that can fulfill equivalent functions.) ISO 14025 lists sets of specific requirements and guidelines for types of data collected, measured and reported in the LCA process (NSF Sustainability, n.a.). After data is collected according to PCR rules, the information is inputted into LCA. Then, EPD summarizes the data analysis from LCA according to the impact categories: climate change, depletion of ozone layer, acidification of land and water sources, eutrophication, formation of photochemical oxidants, depletion of fossil fuel, depletion of mineral resources and generation of hazard and non-hazardous waste.

It is recommended that UBC's Vancouver Campus Plan Part 3 Design Guidelines incorporates the use of EPD's as a design requirement when selecting building materials. Because the data collection methods in creating an EPD are standardized by ISO 14025, qualitative comparison of different environmental product attributes between similar product categories is permissible. This will allow UBC to select not only sustainable materials for their building and landscape infrastructures, but also compare and select the material that qualitatively meets their standards and needs.

2.3 Technical Guidelines

Upon review of UBC's technical guidelines, it is recommended that some details be fixed up for clarity and accuracy. The guideline states that equipment and systems are to be selected based on lowest life cycle cost (LCC), which is a different methodology than life cycle assessment (LCA). LCC supports decision making quantitatively by determining the lowest design life and construction cost whereas LCA is based on the environmental impacts that a building design potentially creates. Therefore, clarity as to which methodology is used should be explained. Moreover, the supporting documents provided, "Energy Rates" and "Maintenance Costs," are tables that contribute more so to a LCC study than a LCA study. In addition, the link for the "Sample Template" for Life Cycle Analysis is a repeated link for the "Maintenance Costs" table. However, the LCA Discussion Document provides a good overview of the LCA methodology and how to integrate it into building design and references LCA correctly. In short, three out of the four documents under the section "Life Cycle Analysis" provide little relevancy to the study. Therefore, it is recommended that an update to this section be done, with perhaps new supporting references be made either from an internal UBC personnel or through LCA-research based websites.

2.4 UBC RFI Evaluation Criteria

Upon review of the RFI document for the Old SUB Building, references to LCA should be made more noticeable in certain sections of the document. This will ensure that the consultants that are answering the RFI understand the client's desire to integrate LCA throughout the design process and produce sustainable results.

The first location would be under 1.2 Request for Information, where the document describes the renewal of existing building systems and that it will follow sustainability objectives and principles. Reference to LCA here is important as LCA will be the primary method of quantifying whether LEED points in sustainability can be achieved.

The second location would be under 3.2.5, under section 7. Project Experience and References. Having consultants that have project experience incorporating LCA into the building design process is beneficial to the project. Consultants that are experienced in working with LCA will understand the analysis procedure, when to communicate and seek consultancy with the LCA consultant, and a familiarity with the sustainable materials that works with and produces good results in LCA. Therefore, it is recommended that reference to LCA should be made in the Project Experience/References section so that members of the project design team will understand the importance of LCA and when to incorporate it into the design process.

2.5 Leed v4

Currently, LEED v4 has included a minimum 3 out of 5 possible LEED points obtainable by utilizing whole-building life-cycle assessment for new construction of buildings. However, meeting this credit is optional and is not required in order to achieve a LEED rating status. Yet, as a client, it is recommended that UBC sets LCA credits for LEED as a mandatory requirement for all new building construction projects. UBC places LEED in high regards because of the school's initiative to renew or construct buildings that are sustainable, green and efficient with its energy usage. Presently, LCA is the only science-based and credible tool that can be used to achieve these goals. LCA is designed to assess the environmental impacts of products gathered for building construction as well as show how different products will interact with the overall building system. By looking at the data analysis from LCA according to the impact categories, building designers can identify trade-offs and opportunities to further improve the building design, either by experimenting with the proposed building's bill of materials or improving the building systems (HVAC, electrical, etc…)

Moreover, UBC's climate action plan is determined to achieve reduced target levels of GHG emission relative to the 2007 GHG level baseline in subsequent years. Similarly, GHG emissions are an impact category that is assessed by LCA. In implementing LCA as a required assessment method for new construction of buildings, not only will the sustainable goals of UBC be met, but also the university's initiative to lower its GHG emission.

3.0 LCA Study of Academic Buildings at UBC Vancouver Campus

3.1 Methods

Throughout CIVL 498C these last few years, Life Cycle Assessment (LCA) has been taught and practiced by students of this course. Through learning about LCA and applying it in practical applications throughout the course, Civil Engineering students were given the task to look at University of British Columbia (UBC) buildings in the perspective of environmental impacts. By looking at the buildings and quantifying its environmental impact, students can get a true sense of how UBC buildings compared to each other over the years. Students also saw how the construction industry impacts the environment in a local scale and subsequently see the implications the construction industry has at a global scale.

In previous years, 4th year Civil Engineering Students taking the LCA course were tasked with multiple practical applications. The final deliverable the students submitted while working on it throughout the course was a compilation of a report and supporting documents for the LCA study of UBC buildings. Through the practicum, students conducted quantity takeoffs for their building by combining the use of structural and architectural drawings and site visits. Using software and the data taken from the drawings and site visits, full building quantity takeoffs could be completed.

After the quantity takeoff data set was completed, the profiles were used to generate LCA models of the whole building in Impact Estimator software. The impact estimator utilizes Athena Life Cycle Inventory (LCI) Database. The standard the students used is the same standard used in the majority of North America for environmental impacts; the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI). By inputting data for each part of the building and modelling the whole building in the impact estimator, Life Cycle Impact Assessments (LCIA) could be calculated.

The main objective was to complete LCA studies and institute material inventories and environmental impact references for UBC buildings. With the references created for all the buildings in UBC, they can be used for assessment of performance upgrades for each building and also be looked at in comparison to understand the differences over the years on what materials, structural types, and building functions have on environmental impacts. The dataset created can also be a strong tool to help UBC develop policies and guidelines for sustainable future construction projects.

In the fall of 2014, the 4th year Civil Engineering Students were also tasked with multiple practical applications. These tasks revolved around the buildings looked at for LCA studies in the previous year. The buildings studied in the previous year and, subsequently, studied this year are listed below:

- AERL (Aquatic Ecosystems Research Laboratory)
- ALRD (Allard Hall)
- ANGU (Henry Angus Building)
- CEME (Civil and Mechanical Engineering)
- CHBE (Chemical and Biological Engineering Building)
- CHEM (Chemistry D Block)
- CHEMN (Chemistry North Wing)
- CHEMS (Chemistry South Wing)
- CIRS (Centre for Interactive Research on Sustainability)
- ESB (Earth Sciences Building)
- FSC (Forest Science Center)
- GEOG (Geography Building)
- HEBB (Hebb Building)
- HENN (Hennings Building)
- ICICS (Institute for Computing, Information and Cognitive Systems)
- KAIS (Fred Kaiser Building)
- KENN (Douglas Kenny Building)
- LASR (Frederic Lasserre)
- MATH (Mathematics Building)
- MCML (MacMillan Building)
- MUSC (Music Building)
- PHRM (Pharmaceutical Sciences Building
- SCRF (Neville Scarfe Building)
- WESB (Wesbrook Building)

Using the data compiled for the buildings by the previous year, and the material taught in class, the students in in CIVL 498C during the fall of 2014 had 3 stages to the final project. The first stage consisted of using the Impact Estimator software from Athena version 5.0. Using this tool, buildings were given a 60 year life cycle and data for the buildings Bill of Material and life cycle environmental impacts were exported. Using this data, baselines of the building could be examined which would give us the information needed to proceed to stage 2 of the project.

Stage 2 was an exercise to create baselines and incorporate possible changes to building components to satisfy LEED requirements. By improving a building's environmental impact by a minimum of 10% in three or more categories, it is possible for a building to obtain three LEED points. There were two baselines buildings created per student, one of which was their original stage 1 building data and the other being all the stage 1 building data averaged. However, for this project, some of the data collected and compiled from previous years caused errors in the calculations and are considered outliers and not included in this year's calculations and analysis. The buildings not included in this year's calculations were the Henning's Building, the Forest Sciences Center, and the Pharmaceutical Sciences Building.

Other than these three buildings that were excluded completely in this year's study, the rest of the data can be considered accurate and reliable enough for the basis of this year's project and deliverables. There are some small assumptions made for the buildings made when input into Athena to model the building in the software as the software has a limited number of options and tools. These assumptions however are reasonable for the use of this project. In future studies, however, it would be beneficial to revisit and update the inputs to improve the accuracy of the data.

3.2 Results

By modifying the model created from the previous year's data, data was compiled for 60 year life cycle impacts and total materials used for each building. The detailed Bill of Materials for each building can be found in excel file referenced in Annex B - Tables. The following table outlines the total mass of the materials in each building.

Building	Total Mass Value	Mass Unit
AERL	8754	Tonnes
ALRD	16841	Tonnes
ANGU	16931	Tonnes
CEME	11494	Tonnes
CHBE	22642	Tonnes
CHEM	16783	Tonnes
CHEMN	4273	Tonnes
CHEMS	8167	Tonnes
CIRS	6904	Tonnes
ESB	4536	Tonnes
GEOG	2253	Tonnes
HEBB	9587	Tonnes
ICICS	20316	Tonnes
KAIS	18221	Tonnes
KENN	14309	Tonnes
LASR	9164	Tonnes
MATH	1107	Tonnes
MCML	42197	Tonnes
MUSC	9692	Tonnes
SCRF	7397	Tonnes
WESB	15003	Tonnes

Table 1: Studied Buildings and their Total Material Mass

Although the summary of the total mass of the building materials do not directly correlate to any environmental impact, these results do give a rough idea. Small buildings usually do have smaller impacts in total, although they may not necessarily be efficient, and lots of lighter building materials in general have smaller environmental impacts as well. An example would be concrete and steel having high densities and materials like timber have low densities.

As can be seen in the appendix, a large portion of these buildings, especially the older ones, are built mainly with concrete. There are a lot of different materials in each building and a lot of them overlap which is expected as the impact estimator assumes certain materials for certain building section. This is also the case because the construction industry as a whole would use similar materials especially in the past. However, even though buildings share many elements, the largest percentage of the mass is usually due to the concrete component of the buildings.

With each building, a full LCA study was conducted last year. This year, the files and data were taken and modified to give impact estimates for the building over a 60 year period. The TRACI method is used and the results of the environmental impact assessments could be calculated. The following graphs are summaries of the total impact of each building assessed per square meter up to the end of the building life. The detailed data on individual components can be found in the excel file referenced in Annex B – Tables.

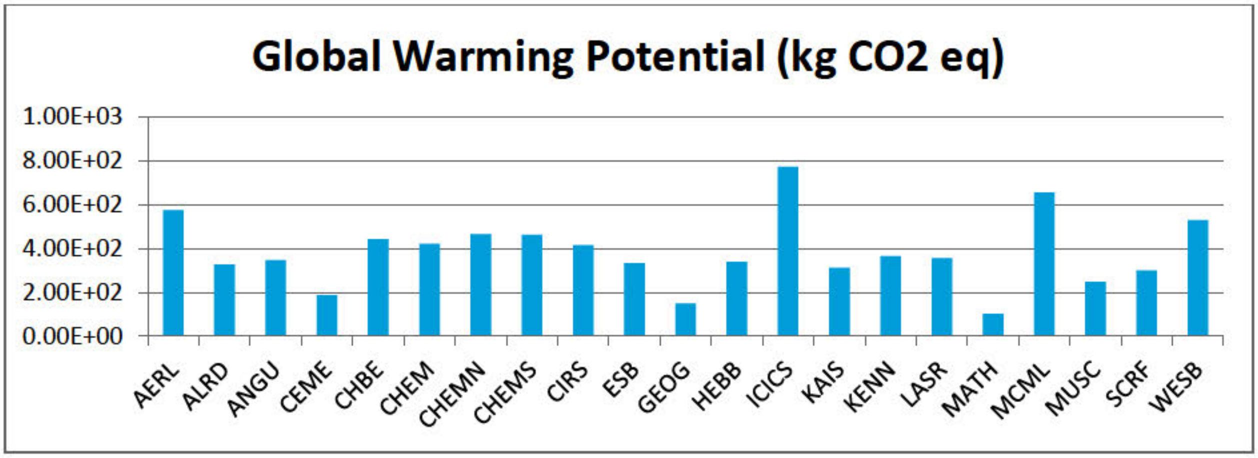

Figure 1: Global Warming Potential of Studied UBC Buildings

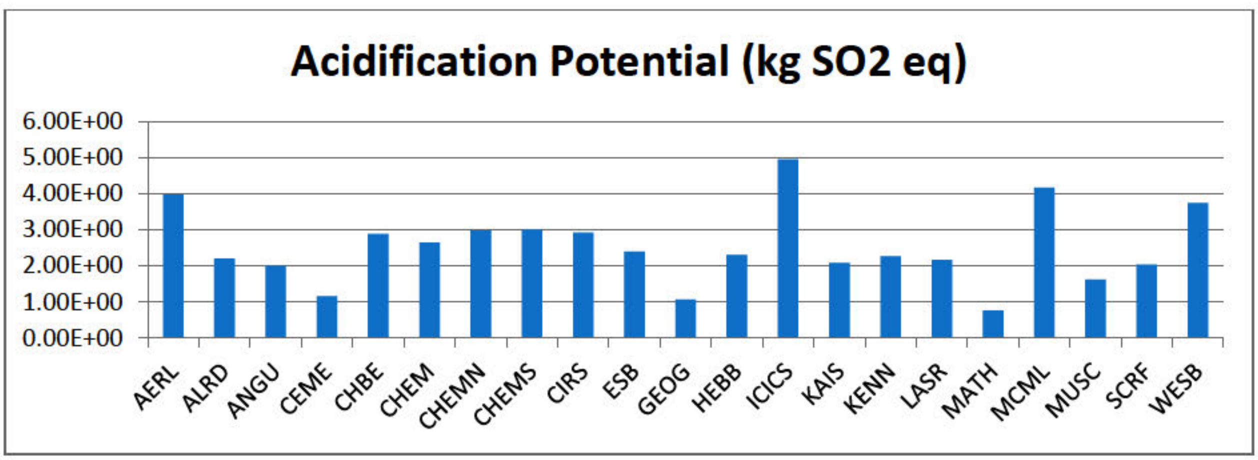

Figure 2: Acidification Potential of Studied UBC Buildings

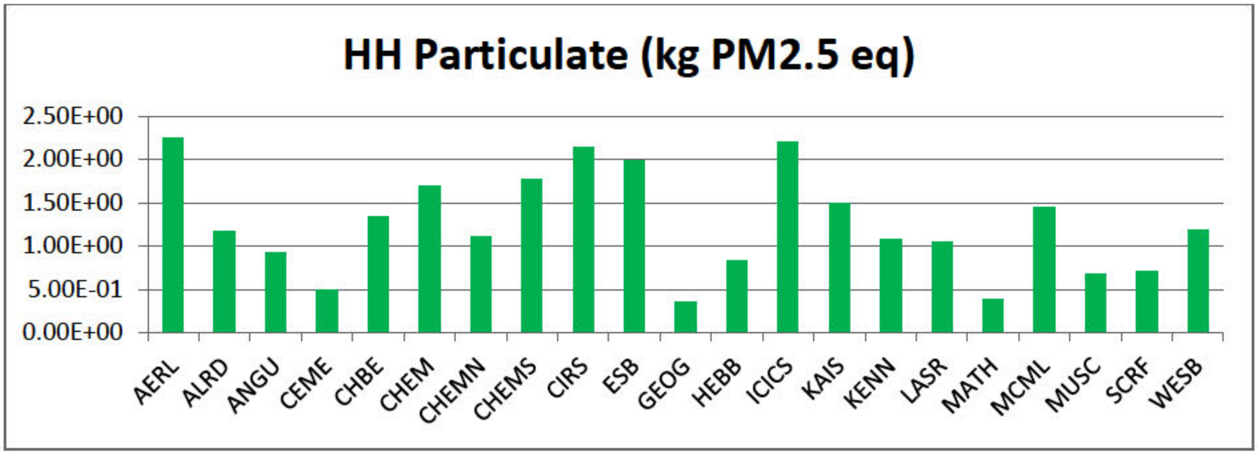

Figure 3: HH Particulate Accumulation of Studied UBC Buildings

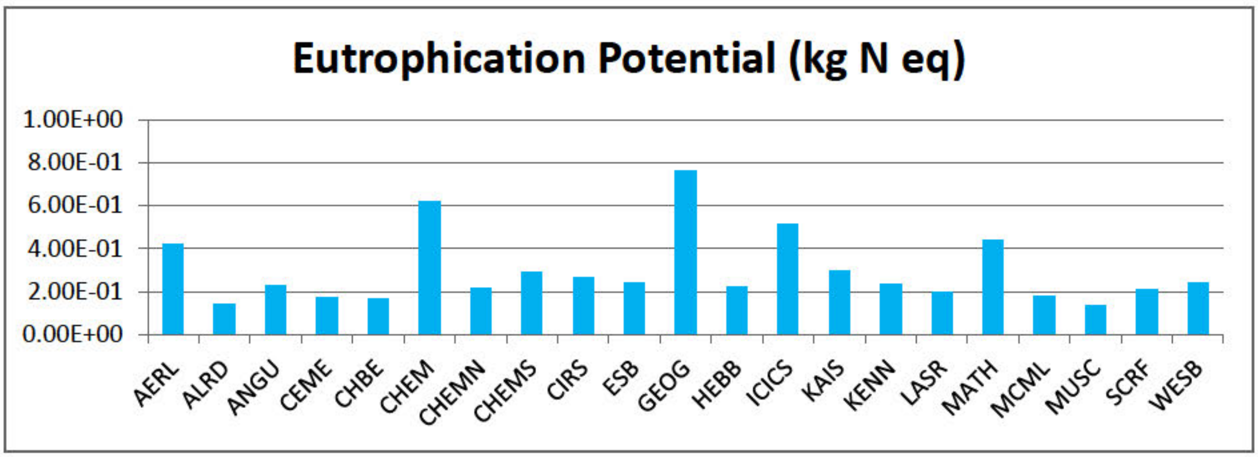

Figure 4: Eutrophication Potential of Studied UBC Buildings

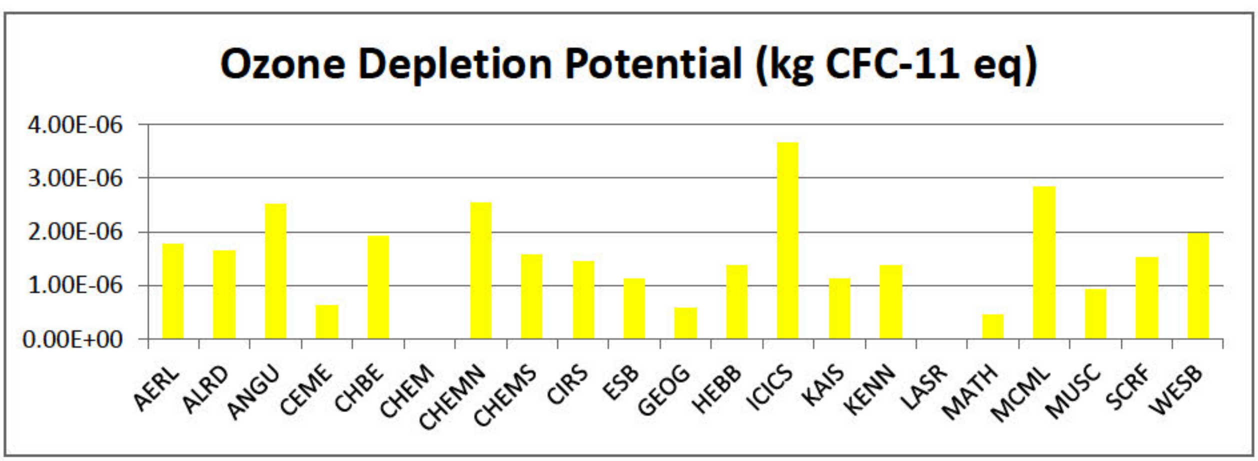

Figure 5: Ozone Depletion Potential of Studied UBC Buildings

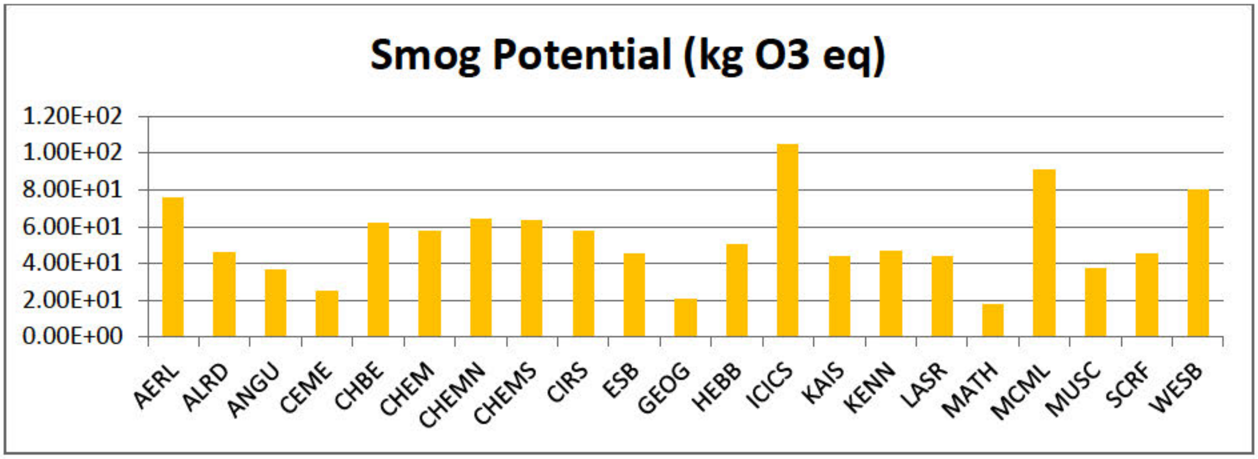

Figure 6: Smog Potential of Studied UBC Buildings

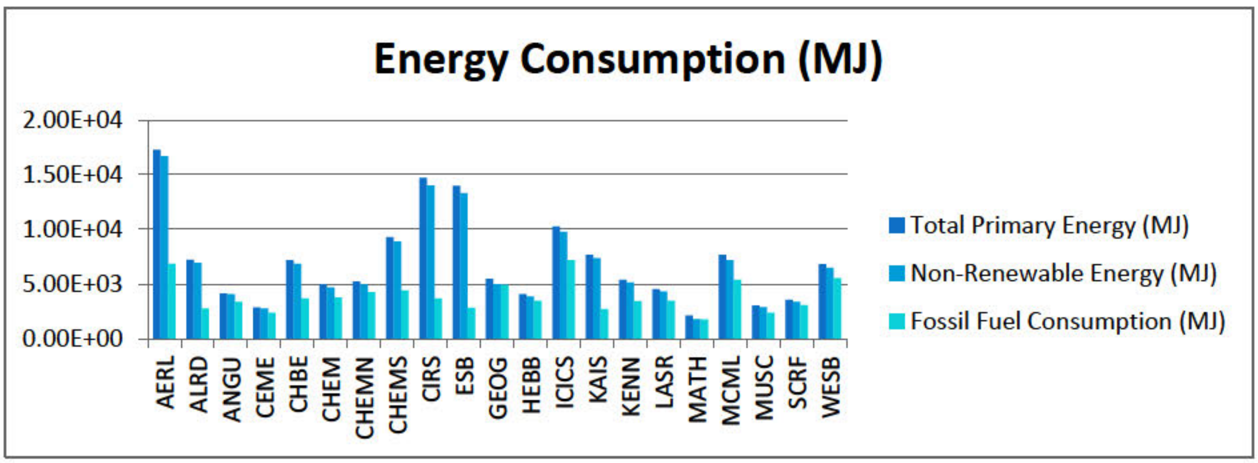

Figure 7: Energy Consumption of Studied UBC Buildings

All the tables are summaries and the detailed breakdown of each component and element can be found in the database included in the submission to course Dropbox. The data is taken directly from the Athena Impact Estimator software.

3.3 Discussion

The results obtained through the impact estimator and processed, in general, show a direct correlation between the size of the building and the total materials used which in turn affect the environmental impact of said building. This is an obvious statement; however, having the evidence to back up the claim is important. This also indicates that almost all building materials used in the past have all had an impact on the environment, therefore the more material needed for the building, the more impact there will be on the environment. This is a key factor in minimizing environmental impacts. In all aspects of the construction industry, there are many architects and design ideas. With these results, it is safe to assume that designs minimizing the use of materials will have lower impacts compared to overdesigning with high material use, especially in terms of complicated designs for aesthetics. This can be clearly seen by the low overall impact of the CEME building. It is a very simply designed building and has one of the lowest impacts per square meter.

Other major components that affect the environmental impact are the choice of material used. By looking at the more detailed data which can be found in the appendix, there is a clear indication that certain materials like regular concrete and steel have large negative impacts, whereas materials like glulam and other forms of timber have much lower environmental impacts. Although it may not be financially feasible to eliminate the use of certain materials, it is clear that using more sustainable options like concrete with higher fly ash content will also lower the environmental impact of the building.

This study on the environmental impacts of UBC buildings can be used as part of a database or baseline in determining the sustainability of future buildings made on UBC's campus. In the future, it can also be extended as more data is collected to include buildings all around Vancouver to improve the sustainability of the city that is being strived for. Another application is to help inform policy makers of how LEED points can be obtained through LCA and how to implement it into the UBC policies without exploiting it. By going through the course and applying the knowledge learned throughout the course in Stage 2 of the project, a clear problem can be seen with how the LEED points are awarded to buildings as of now. To achieve three points from option 4 of the "Building life-cycle impact reduction", the proposed building simply needs to have a 10% reduction in at least 3 impact categories with none exceeding the baseline. (US Green Building Council, 2013) The problem with this is that the baseline building can be simply overdesigned after the fact of the building that was originally designed. This would give the originally designed building 3 LEED points without actually needing to improve or look at improving the design in any form. The overall idea of improving the design to obtain LEED points is a very important idea in continually improving the sustainability of buildings; however, this clearly shows the need of policy makers to make sure the wording cannot be misinterpreted or exploited resulting in the policy not actually providing any improvement

4.0 Next Steps for Institutionalizing LCA at UBC

This section of the report will discuss about the approaches to institutionalize LCA in UBC's building design and operations. The areas of concern are: LCA modeling tools, LCA databases, LCA decision making methods, and LCA communication and educational resources. Each area will consider the best tools and methods for LCA in UBC as well as how incorporate them in a beneficial and efficient manner.

4.1 LCA Modelling Tools

4.1.1 Explanation of Modeling Tools

LCA modeling tools are used as a simple method to account for the environmental impacts of a building or assembly. By inputting the quantity takeoff, LCA modeling tools will indicate the approximate amount of each impact category affected. There is a simple classification system from Athena Institute to better manage the numerous programs available (Trusty and Horst, 2005). Level 1 tools only models individual products or simple assemblies with comparisons to the environmental and/or economical indication of those products or assemblies (Trusty and Horst, 2005). Level 2 tools models the design of whole building and provides information concerning operating energy, lighting, life cycle costing, and life cycle environmental effects (Trusty and Horst, 2005). it is specific to the country the tool is designed for, thus it is recommended that the tools developed in North America be used for UBC's purpose (Trusty and Horst, 2005). Level 3 tools assess a whole building similar to level 2 tools, but include a broader range of frameworks that measure environmental, economic and social concerns in regards to sustainability as well (Trusty and Horst, 2005). However, they use both objective and subjective inputs, and while it provides a more complete outlook on the building; for much of the objective data, level 2 tools are used (Trusty and Horst, 2005). For a more focused LCA study, level 2 tools are recommended as it gives a truer, comprehensive view of impacts then the adjusted one from level 3 tools.

4.1.2 Modelling Tools

Modeling tools suitable for the North American region are BEES and Athena EIE, though tools from other countries such as SimaPro, GaBI, Umberto and TEAM are also useable with the appropriate data (Trusty and Horst, 2005). A level 3 tool for North America is GreenGlobes, though, as the objective results are taken from Athena EIE, it is better to just use Athena EIE instead.

BEES (Building for Environmental and Economic Sustainability) measures the environmental and economic performance of a building, providing a direct comparison of the tradeoffs between the two (Greig et al. 2010). Results obtained in BEES can be viewed at all stages of a life cycle and the environmental flow (Trusty and Horst, 2005). Scores are given in regards to the amount of environmental impact to see which element rank the lowest and is in need of improvement (Trusty and Horst, 2005). Additionally, BEES includes importance weights in their Multi-Attribute Decision Analysis, to better combine the environmental and economic performance to an overall performance measure (Greig et al. 2010). BEES free of charge and is available online via their website. However, BEES is a simple level 1 tool and does not give details on whole building level of design. It is only useful for analyzing and comparing at individual assemblies.

The solution for looking at the LCA for the whole building or complete building assemblies is the software Athena EIE (Athena Environmental Impact Estimator). Athena EIE examines the impacts to the system regarding the product selection of building structure and envelope, ensuring that the building products are compared on a functional equivalence basis (Trusty and Horst, 2005). Eight different regions of Canada are accounted for, unlike BEES, where only U.S. data is used (Trusty and Horst, 2005). Material maintenance and replacement is taken into account in EIE (Trusty and Horst, 2005). Additionally, operational energy can be shown if an energy simulation is provided (Athena Institute, 2014). EIE is very flexible, allowing for custom assembly and envelope configurations to model designs more accurately (Athena Institute, 2014). The cradle to grave implication of a design is region specific and can be viewed in terms of inventory results and summary measures (Trusty and Horst, 2005). Also, these results can be shown at a whole building or assembly or by each life cycle stage (Trusty and Horst, 2005). EIE includes an "End of Life" demolition module and can accommodate multiple comparisons at the same time as well (Athena Institute, 2014). Overall, this user-friendly software is the most important tool for LCA in North America.

A simple search shows that many other LCA tools are in the market as well, though many are targeted to products LCA and not green buildings. The problem with some other software lies in the dataset they adopt, as many are developed in Europe. Some examples are: EarthSmart, Sustainable Minds, openLCA and Umberto.

4.1.3 Tools for UBC

The tools in LCA are still developing and many tools currently complement each other, as they are useful in different stages (i.e. screening for assembly vs. a whole building). Moreover, a major issue with LCA is the availability and quality of data, so different tools may have overlapping as well as different data sets. This is why using multiple tools to compare and confirm result is beneficial. Nevertheless, Athena EIE is the most developed among the North American software and it is a necessary modeling tool recommended to be used in a complete, official LCA report for future UBC projects.

4.2 LCA Databases

There are quite a few databases for LCI (Life Cycle Inventory): the US LCI, Athena LCI Database, ELCD (European reference Life Cycle Database), EcoInvent, and GaBi. UBC should use caution if or when utilizing the databases ELCD, EcoInvent, and GaBi. The data from ELCD is collected in Europe and is therefore irrelevant to Canada. This is the same for EcoInvent and GaBi as well, as they are databases from Switzerland and Germany respectively. Although both databases stated that they have now included some global data, it is uncertain how much of the North American data is in their present versions.

4.2.1 Relevant Databases

The US LCI is a very comprehensive and user-friendly, providing individual gate-to-gate, cradle-to-gate and cradle-to-grave accounts of energy and material flows from producing a material, component, or assembly in the US (NREL, 2013). It is accessible online and is divided into sections of dataset type, category, and year for simple navigation. A search bar is also available on the page.

The Athena Institute developed a LCI Database as well, with most of their research at Athena contributing to developing, verifying and updating the databases (Athena Institute, 2014). The data incorporated in the EIE is from this in-house data developed in cooperation with industry associations (Athena Institute, 2014). Most of their data is not publicly accessible, as the data is proprietary to those associations in the industry; however, some publications in LCA studies and LCI product reports are available online (Athena Institute, 2014).

The Life Cycle Assessment course (CIVL 498C) at UBC accumulated the data of UBC buildings over some years and can be used as a benchmark for future projects. The information collected and analysed is valuable to the development of LCA in UBC. However, it would be useful to have a professional to audit the data as it would seem that some of it is flawed.

4.2.2 Impact Assessment Methodology

There are Impact assessment methodology such as Eco-indicator 99, EDIP97, EDIP2003, EPS 2000d, LCA Handbook (Dutch), IMPACT 2002(+),ReCiPe, ECOSCARCITY (Swiss), JEPIX, and TRACI. Most of these methodologies use the midpoint method with normalization or using the damage approach, others uses endpoint methods and have weighing methods based on policy. The midpoint method presents the qualitative relationships resulting from the inventory information from LCI. The qualitative results are shown in their relative impact categories such as: global warming, ozone depletion, acidification, eutrophication, smog potential, human health, land use, non-renewable resource, toxicity and fossil fuel. Endpoint methods such as Eco-Indicator 99 are weighted and have an entirely different scope and structure from midpoint methods. Endpoint methods are more subjective and larger in scope as it extends the model to include the endpoint affects it has to the environment (such as increasing a fraction of disappeared species) rather than just the quantity of pollution released into the environment.

As the two major types of methodology uses entirely different in scope and structure, they may provide entirely different results. As TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) is the one used most commonly in North

America, it is recommended to be used for UBC purposes. TRACI is a midpoint model that can store inventory data, classify stressors into their impact categories, and characterize for those categories (Bare and Cloria, 2005).

4.2.3 Environmental Product Declaration (EPD)

Another type of data is EPDs. EPD stand for Environmental Product Declaration and it is a verified document with quantified environmental data for products based on LCA and other additional relevant environmental information (EPD International AB). They are useful on providing data needed for an LCA.

4.2.4 Suggestions to UBC

UBC should keep UBC's own database of buildings updated, while keeping in mind there are always updated information from relevant databases. UBC may need to actively keep track of major updates or only need do a throughout research when the LCA of a project requires for it. In any case, the tools recommended in this report updates their databases regularly as new methods or innovations of manufacturing and/or production calls for new data.

4.3 LCA Decision Making Methods

4.3.1 Application of Weights in LCA

Weights are needed for measuring the importance of categories of impacts as the quantity of impacts does not represent their severity. What may be an important environmental issue now may not be an important issue in the past or future (i.e. global warming).

As previously mentioned, BEES uses weights via the AHP method (Cooper et al, 2007). The weight draws on the individual's understanding of the values for each impact category, and overall reflecting a contemporary view on the importance to each (Cooper et al, 2007). BEES also accounts for the economic performance using the ASTM International standard life-cycle costing method combining with the environmental performance for a total score using Multi-

Attribute Decision Analysis (Cooper et al, 2007). A weight set is developed with selected panelists (the producers, the users, and the LCA experts) matching with the issues of today (Cooper et al, 2007). The weighs are: global warming (29%), fossil fuel depletion (10%), criteria air pollutants (9%), water intake (8%), human health cancerous effects (8%), ecological toxicity (7%), eutrophication (6%), land use (6%), human health non-cancerous effects (5%), the others, smog formation, indoor air quality, acidification, and ozone depletion have the lowest rates (Cooper et al, 2007).

The LCA study for UBC BioScience included weights as well. The report seeks to weight avoided impacts from renovation if the Built New scenario is not pursued (Athena Institute et al, 2011). Athena, the consultant for the study, weighted fuel and water inventory in regards to the request, saving an estimate of $255,000 with 6% avoided BC carbon taxation (Athena Institute et al, 2011). The method of the weighting is explained in the appendix of the study.

4.3.2 Considerations for UBC

Different environmental impacts as well as economic and social factors play an important role in decision making for projects. LCA only provides part of the picture, therefore UBC can consider using weights and developing a life-cycle cost analysis (LCCA) in addition to LCA, as they will provide more insight to make a better, informed decision.

4.4 LCA Communication and Education Resources

4.4.1 Internal and External Uses

There are many uses for an LCA report, from providing an informed decision to using it as marketing tool. Internally, LCA can be used to identify the bottlenecks (environmental hot spots) of a project and compare the alternatives of those critical items (Frankl, 2001). Externally, LCA can be used to market as a certification of a green building, but this is impractical as of now, as LCA is not widespread and is too complex to be fully understood by the general public (Frankl, 2001). Nevertheless, it is still useful to inform and influence suppliers, industrial clients and stakeholders about the improvements achieved using LCA (Frankl, 2001).

4.4.2 Institutionalization Theory

The institutionalization theory for introducing a new phenomenon into business can be applied here (Frankl, 2001). The theory is divided into three stages: 1) habitualization stage, 2) objectification/ semi-institutionalization stag, 3) full-institutionalization/sedimentation stage (Frankl, 2001). In the first stage, the idea/application only exists in a small part of the institution (i.e. environmental department) where people are mainly learning about the application and using it retrospectively (Frankl, 2001). While in the semi-institutionalization stage, the idea becomes more wide-spread among the whole institution and people shift from retrospective to prospective uses (Frankl, 2001). Finally, the application is systematically integrated with business activities, where it becomes a routine tool (Frankl, 2001).

Other important success factors are 'the presence and influence of an entrepreneur who pushes LCA activities, the mandate of top-management, the involvement of practitioners and lastly, the development of formalized structure, internal communication channels, internal know-how and a long term environmental commitment' (Frankl, 2001). The entrepreneur is very important in the initial two stages as he/she is the initiator for the discussion about LCA, demonstrating the importance of the application and creating a consensus around it (Frankl, 2001). The mandate of the top management is also crucial to the success of institutionalization as the institution cannot move forward with LCA without an approval at that level (Frankl, 2001). Additionally, the effort in enlarging the consensus as well as the involvement and motivation of the people though good communication means are necessary (Frankl, 2001). These key factors will aid LCA into becoming an every-day support tool for decision making (Frankl, 2001).

LCA institutionalization can also bring about other initiatives such as individual component improvements to the building or system improvements and collaborative efforts with other companies or research institutes (Frankl, 2001). LCA can generate short-term and long-term innovations as improving one building will build up more ideas on where the hot spots are and how they need change, providing guidelines to the next cycle of new buildings (Frankl, 2001).

4.4.3 LCA Studies in UBC

UBC has already applied LCA in a few projects, one of which is the Buchanan Building D renovation (phase 1) (AltusHelyar et al, 2006). Athena EIE was used for LCA analysis comparing different models for the renovation and the new building scenarios (AltusHelyar et al, 2006). The models are developed for each stage: full demolition, demolished materials, retained components, renovation work, and the new building (AltusHelyar et al, 2006). Another LCA study in UBC is of the District Energy Centre (Hot water plant) (Coldstream Consulting, 2013). In this study the Athena LCI Database and the software TRACI were used for the impact assessment.

The most detailed LCA report is UBC's Biological Sciences Complex Renew Project. The methods and environmental benefits are transparent and comprehensible in the report (Athena Institute et al, 2011). It is an excellent example of how future UBC building construction projects can model an LCA study (Athena Institute et al, 2011). The method and terms are explained throughout the way and there are even figures to demonstrate the concepts (Athena Institute et al, 2011). The software Athena EIE and the data from CIVL 498C class is used for modeling and the benchmark respectively (Athena Institute et al, 2011). As mentioned above, a weight is included on the resources for the avoided impact from the decision to renovate instead of rebuilding (Athena Institute et al, 2011). This provides a demonstration of the incorporation of weights in LCA. Clear graphics and tables comparing to the benchmark and alterative options also aid in the transparency of the study. The report suggests UBC Project Services to continue to investigate renovation verses build new by requesting the completion of LCA on Renewal Projects (Athena Institute et al, 2011). Earlier requests would also aid in the decision making process (Athena Institute et al, 2011). Another recommendation for UBC's Project Services is to standardize Goal & Scope and Interpretation guideline to better regulate future LCAs (Athena Institute et al, 2011).

4.4.4 Education and Communication Recommendations

These LCA reports from UBC are reproducible and are excellent educational resource of using LCA for the whole building process. A suggestion for providing good practice for LCA is to adhere to the recommendations in the Biological Science document, as it will standardize

LCA and make for a better system in UBC. It would be beneficial to provide an educational package of LCA with the main concept and terminology and including an example for a report to future building project builders and any major UBC stakeholders. It would be helpful if information about the programs used in these studies are Athena EIE and TRACI are given as well. The CIVL 498C class also provides useful resource for LCA in terms of a benchmark for the current buildings in UBC and a presentation about LCA every year.

Communication is key to institutionalize LCA in UBC. As mentioned above, an important success factor is the 'entrepreneur' who pushes LCA activities as well as the involvement of practitioners in UBC. It is recommended that any individual interested in LCA strongly promote or ask questions about LCA to create conversation about LCA and eventually reach a consensus about institutionalizing. The development of a formalized structure of LCA is needed for UBC as well. Recommendations regarding a formalized structure are stated in the BioScience report to UBC Project Services, explained above. If needed, UBC can set a requirement to include LCA studies at least for the initial screening phase of projects. Further communication channels with the LCA Communities such as the American Centre for Life Cycle Assessment and UN Life Cycle Initiative would be valuable as well.

5.0 Conclusion

Currently, UBC has developed many sustainability action plans and technical guidelines and standards for building design and construction. These documents were developed with the goal in constructing much more sustainable buildings that will also be energy efficient and produce minimal waste. However, many of these documents reference minimally to LCA, which is the only science-based tool to quantitatively support sustainable building design decisions. Recommendations as well as rationalizations to further incorporate LCA into Climate Action Plan, Vancouver Campus Plan Part 3 Design Guidelines, Technical Guidelines, UBC RFI Evaluation Criteria, and LEED v4 have been made in the report. In turn, LCA will be able to have a bigger presence in UBC building design and operations, resulting in construction of greener, more sustainable infrastructures in the future.

Next, quantity takeoffs and LCA studies from previous years for Civil 498c were for individual UBC Buildings, which was then used to improve overall sustainability of buildings on campus. However, this year's class objective uses LCA studies done by previous years to observe how current UBC buildings are impacting the environment and how materials and design components will affect impact categories from each building. The results from this year's projects give a good insight on how easily LEED points can be awarded without substantial reduction in environmental impacts. Moreover, the results from this year's study can be used by UBC to update current building design and operations standards so that they are up-to-date to current capacity demands.

The next step to institutionalize LCA is to consider LCA tools, databases and LCIA methods. Suitable programs, such as Athena EIE and TRACI, are researched in order to programs that will meet the client's project scope and goal. Decision methods and weighting criteria are also considered to meet UBC's Green Building initiative. Recommendations for institutionalizing LCA in UBC are based on success factors such as an entrepreneur who pushes LCA initiatives, the involvement of practitioners and development of a formalized structure. Suggestions to educational and communication initiatives are developed while keeping the success factors in mind.

6.0 Works Cited

AltusHelyar, Busby Perkins + Will, July 2006, Life Cycle Assessment - Buchanan Building D, http://civl498c.wikispaces.com/file/view/2006.07.12_Buchanan_LCA_Report.pdf/528036092/2006.07.12_Buchanan_LCA_Report.pdf (Nov 18, 2014)

Athena Sustainable Material Institute, 2014, Impact Estimator for Buildings, http://calculatelca.com/software/impact-estimator/ (Nov 18, 2014)

Athena Sustainable Materials Institute, Recollective Consulting, Jul 25, 2011, Life Cycle Assessment of UBC Biological Sciences Complex Renew Project, http://civl498c.wikispaces.com/file/view/BioSciences%20LCA%20Study_Final_SUBMITTED.pdf/527731376/BioSciences%20LCA%20Study_Final_SUBMITTED.pdf (Nov 18, 2014)

Bare, J., Gloria, T., Nov 2005, Progress Report on Life Cycle Assessment, Life Cycle Impact Assessment for the Building Design and Construction Industry http://civl498c.wikispaces.com/file/view/Assignment%231_BD%26C%20White%20Paper.pdf/521690924/Assignment%231_BD%26C%20White%20Paper.pdf (Nov 18, 2014)

Coldstream Consulting, Mar 7, 2013, LCA Study of the UBC District Energy Centre - Hot Water Plant, http://civl498c.wikispaces.com/file/view/2013-03-07%20DEC%20Stage%201%20Report.pdf/527731442/2013-03-07%20DEC%20Stage%201%20Report.pdf (Nov 18, 2014)

Cooper, J., Gloria, T.P., Lippiatt, B.C., Oct 2, 2007, Life Cycle Impact Assessment Weights to Support Environmentally Preferable Purchasing in the United States, http://civl498c.wikispaces.com/file/view/%28Gloria%20et%20al%2C%202007%29_LCIA%20weights%20to%20support%20environmentally%20preferable%20purchasing%20in%20the%20US.pdf/528035304/%28Gloria%20et%20al%2C%202007%29_LCIA%20weights%20to%20support%20environmentally%20preferable%20purchasing%20in%20the%20US.pdf (Nov 18, 2014)

Dreyer, L.C., Niemann, A.L., Hauschild, M.Z., Jul 2003, Comparison of Three Different LCIA Methods: EDIP97, CML2001 and Eco-indicator 99, http://link.springer.com/article/10.1007%2FBF02978471 (Nov 18, 2014)

EPD International AB, What is an EPD?, http://www.environdec.com/en/What-is-an-EPD/#.VGzlwfnF-Sp(Nov 18, 2014)

Frankl, P., 2001,The Contre for the Management of Environmental Resources, Life Cycle Assessment as a Management Tool, 2001/92/CMER, http://civl498c.wikispaces.com/file/view/Frankl%2C%202000.pdf/528033598/Frankl%2C%20200.pdf (Nov 18, 2014)

Green Building Initiative, 2014, Green Building Programs, Green Globes Program Features: Life Cycle Assessment& Multiple Attribute Evaluation, http://www.thegbi.org/green-globes/life-cycle-assessment.shtml (Nov 18, 2014)

Hal Levin, 2014, Life Cycle Assessment Software, Tools and Databases, http://www.buildingecology.com/sustainability/life-cycle-assessment/life-cycle-assessment-software (Nov 18, 2014)

Huffman, A., Mark, Lucuik, Prefasi, A., Trusty, W., 2010, The Greenest Building Is the One That Is Never Built: A Life-Cycle Assessment Study of Embodied Effects for Historic Buildings. p. 8-9

Lippiatt, B., Greig, A. L., Lavappa, P., 2010, BEES, http://www.nist.gov/el/economics/BEESSoftware.cfm (Nov 18, 2014)

National Renewable Energy Laboratory, Nov 18, 2013, U.S. Life Cycle Inventory Database, http://www.nrel.gov/lci/(Nov 18, 2014)

NSF Sustainability, n.a., *Product Category Rules, Life Cycle Assessments and Environmental Product Declarations*, http://www.nsf.org/newsroom_pdf/SU_PCR_EPD_White_Paper_LT_EN_LSU27230612.pdf. (November 15, 2014)

Trusty, W., Horst, S., Nov 2005, Progress Report on Life Cycle Assessment, LCA Tools Around the World,*http://civl498c.wikispaces.com/file/view/Assignment%231_BD%26C%20White%20Paper.pdf/521690924/Assignment%231_BD%26C%20White%20Paper.pdf (Nov 18, 2014)*

United States Environmental Protection Agency, May 8, 2014, Risk Management Sustainable Technology, *LCA Resources, http://www.epa.gov/nrmrl/std/lca/resources.html#Software (Nov 18, 2014)*

US Green Building Council, 2013, *Option 4, whole-building life-cycle assessment*, Leeds v4 for Building Design and Construction, p 90

Annex A1 – Author Reflection (Eric Ho)

Prior to taking CIVL 498C, my exposure and experience with LCA was very limited. I had barely heard of it short of a single lecture and small references to it during my other courses taken in previous years. As a co-op student that worked closely with engineers in the construction industry, LCA had little to no mention in my workplace. In short it before this course, I knew almost nothing about LCA.

Throughout the course, I continually learned through lectures, guest speakers, and practical application of LCA methodology. Besides learning the basic terminology and the steps to completing an LCA study, I have also learned about international LCA standards and how they have been translated and imported to North America. The differences in international standards are also compounded by the fact there are multiple databases being used across North America. Although it is great there is competition meaning there are clear signs of progress with LCA studies, this also poses as a problem with standardizing LCA studies.

By learning about LCA, it has also enabled us to read and understand LCA studies and to provide critical feedback on them and claims to sustainability. The term sustainability has been used very loosely recently and can be a cause of a lot of questions and confusion. With the knowledge obtained in this course, it is easy to quantify environmental impacts and objectively show and analyze if something truly is sustainable.

Furthermore, through the practical parts of this course, I have learned how to use LCA software like the Athena Impact Estimator. Using impact estimators like this and inputting designs into it can give designers an idea of the impact their project will have on the environment, this is a powerful tool in how to design low impact buildings and obtain LEED points.

The most interesting part of the course has been the practical aspect. Learning powerful and useful tools for LCA studies like Athena Impact Estimator. Overall, however, it has been the fact that this course gives a practical way in quantifying environmental impacts and objectively being able to look at buildings and how sustainable they are.

One of the revelations or things I learned that really surprised me is how long LCA has been around. Although it started quite a long time ago, it only started gaining traction in the construction industry

	Graduate Attribute			
	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe were addressed during your class experience. Reflect on the experiences you got from the games, lectures, assignments, quizzes, guest speakers organized for the class, and your final project experience.
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	IDA = introduced, developed & applied	

2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	DA = developed & applied	
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.		

4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	DA = developed & applied	Although not an actual design course. This course teaches us how to modify and design buildings that have smaller environmental impacts.
5	Use fo Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools	DA = developed & applied	Taught us to use an impact assessment tool in which data was inputted and an output was generated and that we needed to assess the outputted data and utilize the program to improve on the output results.

		to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.		
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.		Assignments and Stages have a mix of teamwork and individual work.
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and	DA = developed & applied	Working in groups need clear and effective communication. Course is also only once a week so email correspondence with the professor and TA is crucial

		write effective reports and design documentation, and to give and effectively respond to clear instructions.		
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	DA = developed & applied	Protection of public and public interest. Pollution in air is bad for the public, etc.

9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	DA = developed & applied	Environmental focused course.
10	Ethics and Equity	An ability to apply professional ethics,	DA = developed & applied	sustainability is a hot topic in recent years especially in the construction industry. This course helps us decide on the

		accountability, and equity.		ethics of leaving a better place for future generations.
11	Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	D = developed	Economics is always a part of the building industry. It was highlighted especially in a guest lecture talking about life cycle costs analysis.
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	DA = developed & applied	

Annex A2 – Author Reflection (Jordan Kwun)

1) I previously had very little exposure to sustainability and did not even know a method called life cycle analysis existed. I have heard of the term life-cycle costing, where a project manager looks at the start-up costs, operations cost, maintenance cost and “end-of-life” shutdown costs. But to quantitatively assign points to different environmental impacting categories to products and to make decisions based on this was something that I had not been exposed to before.

Civil 498C has taught me the underlying methodology and workings of life-cycle analysis. ISO 14040 are the guiding standards of the LCA Framework. The framework consists of “Goal and Scope definition,” “Inventory Analysis,” and “Impact assessment”. The goal and scope is a critical procedure because it defines the boundary of the LCA study and provides a framework so that the LCA practitioner will know what to consider for the assessment of the product system. We then learned about inventory analysis, which measures the physical inputs and outputs from the product system. Usually, these inputs are done by quantity take-offs on construction drawings. Finally, the outputs (which are impact categories of environmental concern) are assigned environmental significance and then analyzed so that a better understand of the overall product system is achieved. These findings can also be summarized in an EPD for future clients to read and consider. There are numerous tools out there that perform this task, including Athena Impact Estimator. Certain LCA tools are region specific and so care and understanding of the tool must be exercised prior to use.

2) The study of the LCA framework is what interested me in this class. I found it fascinating to understand how individual data are compiled and processed during the inventory analysis and then categorized and normalized in the impact assessment method. It was eye-opening to understand how to quantitatively decide whether a design is more sustainable than another as well as how changing certain aspects of a design can quantitatively alters its sustainable features. From the project, I got to understand how LCA is being implemented into an organization such as UBC and the challenges of trying to institutionalize LCA into major building plans of UBC.

3) Special interest is the practicality part of the course. It was a pleasure to use collected data and run them through an LCA tool such as Athena to generate environmental impact results to see how sustainable a UBC building was, and then allowing us to alter some materials to see if we

could further improve the results. One revelation that I came to appreciate was how less of a presence LCA was in the building construction industry and the difficulties of trying to convince client corporations to try to implement them into their corporate plans and standards.

	Graduate Attribute			
	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe were addressed during your class experience. Reflect on the experiences you got from the games, lectures, assignments, quizzes, guest speakers organized for the class, and your final project experience.
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	IDA = introduced, developed & applied	
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and	DA = developed & applied	

		solve complex engineering problems in order to reach substantiated conclusions.		
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.		
4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal	DA = developed & applied	Designed a set of material quantities and inputted them into an impact estimating tool which assessed the environmental impact quantitatively. Compared the results fo LEED which required a percentage of reduction in environmental impact from its original building's environmental impacts.

		considerations.		
5	Use fo Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	DA = developed & applied	Taught us to use an impact assessment tool in which data was inputted and an output was generated and that we needed to assess the outputted data and utilize the program to improve on the output results.
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.		Homework assignements and problem solving which required individual work as well as group work.
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes	DA = developed & applied	Applying studied terminology and techniques to a imaginary scenario. Then communicating and conveying these studied terminology and techniques to a

		reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.		public reader in order to convey a message or a response from them.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	DA = developed & applied	The studied method assess environmental impacts and encourages us to understand and perform practices that are positive to human health.
9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an	DA = developed & applied	

		understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.		

Annex A3 – Author Reflection (Jennifer Law)

1) I attended a previous LCA presentation before by the CIVL 498C class two year prior by chance. I was interested in the concept of LCA then as I liked the idea that environmental, cost effective decisions can be made without losing functionality simply by doing an LCA study. It covers all the necessary aspects to make decisions that maintains (and even improves) efficiency with added benefits. I thought that the future of green buildings will be impossible to do without considering LCA. After all, LEED is only a checklist; it does not look at the whole picture. Also, the concept of LCA is simple and it made sense to me.

2) The topics I found to be important in this course are the four main phases of LCA: Goal and Scope, Life Cycle Inventory, Life Cycle Impact Assessment, and Interpretation. I also enjoyed the history of LCA and related environmental issues as well as the problems of institutionalizing

LCA into building practices. There is not a lot of incentive to pursue LCA studies/reports as it is not widely recognized, completely transparent and simple for others to understand.

This report covers the means to incorporate LCA in UBC building practices and the LCA study that is collected from all UBC buildings.

3) I think that LCA still has a lot of issues, but I feel that they will be solved in time once it is more widely accepted and with more complete data. I found it baffling that North America only really has Athena EIE and TRACI to use while Europe has dozens or programs, datasets and software. North America is quite behind on this aspect. Another problem is that there are limitations with the system now - regional, data availability, data age.... etc. It is also very subjective in certain parts like the benchmark and the weighting. I believe the benchmarking should be regulated in the future. The percentage reduced or saved in comparison to the benchmark should be regulated somehow as well. Right now however, LCA is not as widespread and not as glorious to market compared to LEED.

Graduate Attribute Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe were addressed during your class experience. Reflect on the experiences you got from the games, lectures, assignments, quizzes, guest speakers organized for the class, and your final project experience.

1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	IA = introduced & applied	Though the math may not be 'calculus level' math, it is very engineering related with many concepts special to the sustainability side of green buildings. The course also points out issues with LCA, such as social acceptance issues, data quality/availability issues, human-related issues due to subjective procedures in LCA.
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	IA = introduced & applied	LCA procedures are identified in class and we did some games/exercises to solve the LCA for making paper airplanes vs floating device. Other LCA problems are introduced in lectures, though there is no solution yet and people are figuring it out as they go. It is still a new concept, so it will take some time for it to be fully incorporated to our system.
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.	IA = introduced & applied	Although we did not go to the site and take measurements like previous years, we investigated last year's reports, analyzed and interpreted their data on the Athena EIE program and with Excel.

4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	IDA = introduced, developed & applied	There are lectures introducing the complex problem with successfully incorporating LCA and also issues with some methods within LCA itself. The final project ask to design possible solutions to this problem with considerations to economic, environmental, cultural and societal.
5	Use fo Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	I = introduced	The Athena EIE program is introduced in this course, though not applied to the extent it could have. Also, the program is not made to apply for a range of engineering activities.
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	DA = developed & applied	There were lots of group work throughout this course, whether it's the final project or the in-class exercises.

7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	IDA = introduced, developed & applied	Specific LCA concepts and terminologies are introduced and applied. We ere tested on these concepts and terminologies and now they are used in the final report.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	IA = introduced & applied	Many lectures cover this attribute, and we are writing a report for the Green Building Manager at UBC
9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	IDA = introduced, developed & applied	LCA is a course that specifically look at reducing/selecting the optimum solution in regards to lessening the environment impacts caused by human products. Institutionalisation of LCA brings an impact to society as well.

10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	DA = developed & applied	It is mentioned implicitly in lectures and is expected of us in general.
11	Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	I = introduced	There is a lecture on the LCCA and disscussions of when LCA should be used in the decision making process is often stressed.
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	ID = introduced & developed	There are still many issues with LCA, but there are also many innovations and development surrounding it. LCA will keep on developing in the future. Many information is still new and there's always more to learn.

Annex B – Tables

Due to the amount of paper required for this part to be printed, we have included certain tables and the rest of the detailed excel work (which includes calculations) can be found in the excel sheet "Final Project Excel Work.xlsx" in each group member's Dropbox.

Impact Assessment Results Up to Building Life (per m^2)									
Building	Global Warming Potential (kg CO2 eq)	Acidification Potential (kg SO2 eq)	HH Particulate (kg PM2.5 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O3 eq)	Total Primary Energy (MJ)	Non-Renewable Energy (MJ)	Fossil Fuel Consumption (MJ)
AERL	5.75E+02	3.98E+00	2.25E+00	4.19E-01	1.77E-06	7.52E+01	1.73E+04	1.67E+04	6.86E+03
ALRD	3.26E+02	2.21E+00	1.17E+00	1.44E-01	1.64E-06	4.58E+01	7.24E+03	6.92E+03	2.74E+03
ANGU	3.46E+02	2.00E+00	9.16E-01	2.28E-01	2.53E-06	3.65E+01	4.13E+03	4.05E+03	3.36E+03
CEME	1.87E+02	1.16E+00	4.93E-01	1.70E-01	6.33E-07	2.46E+01	2.86E+03	2.74E+03	2.37E+03
CHBE	4.43E+02	2.88E+00	1.34E+00	1.68E-01	1.93E-06	6.16E+01	7.18E+03	6.84E+03	3.69E+03
CHEM	4.22E+02	2.65E+00	1.69E+00	6.17E-01	0.00E+00	5.71E+01	4.93E+03	4.67E+03	3.78E+03
CHEMN	4.65E+02	2.99E+00	1.11E+00	2.18E-01	2.53E-06	6.39E+01	5.22E+03	4.94E+03	4.28E+03
CHEMS	4.62E+02	3.01E+00	1.78E+00	2.93E-01	1.56E-06	6.36E+01	9.27E+03	8.88E+03	4.41E+03
CIRS	4.16E+02	2.92E+00	2.14E+00	2.66E-01	1.44E-06	5.75E+01	1.47E+04	1.40E+04	3.69E+03
ESB	3.32E+02	2.40E+00	1.98E+00	2.39E-01	1.11E-06	4.49E+01	1.40E+04	1.33E+04	2.84E+03
GEOG	1.49E+02	1.07E+00	3.55E-01	7.63E-01	5.75E-07	2.05E+01	5.46E+03	4.98E+03	4.92E+03
HEBB	3.39E+02	2.31E+00	8.25E-01	2.23E-01	1.36E-06	5.06E+01	4.05E+03	3.86E+03	3.46E+03
ICICS	7.74E+02	4.96E+00	2.21E+00	5.14E-01	3.64E-06	1.05E+02	1.03E+04	9.77E+03	7.21E+03
KAIS	3.11E+02	2.09E+00	1.50E+00	2.95E-01	1.11E-06	4.34E+01	7.67E+03	7.37E+03	2.69E+03
KENN	3.64E+02	2.26E+00	1.08E+00	2.32E-01	1.37E-06	4.69E+01	5.38E+03	5.14E+03	3.42E+03
LASR	3.56E+02	2.16E+00	1.04E+00	1.98E-01	0.00E+00	4.35E+01	4.53E+03	4.31E+03	3.44E+03
MATH	1.02E+02	7.66E-01	3.91E-01	4.40E-01	4.58E-07	1.76E+01	2.13E+03	1.79E+03	1.75E+03
MCML	6.54E+02	4.17E+00	1.44E+00	1.78E-01	2.83E-06	9.06E+01	7.66E+03	7.18E+03	5.39E+03
MUSC	2.47E+02	1.63E+00	6.76E-01	1.37E-01	9.33E-07	3.74E+01	3.04E+03	2.88E+03	2.38E+03
SCRF	3.00E+02	2.04E+00	7.10E-01	2.10E-01	1.51E-06	4.48E+01	3.56E+03	3.36E+03	3.08E+03
WESB	5.30E+02	3.75E+00	1.19E+00	2.38E-01	1.96E-06	7.98E+01	6.80E+03	6.49E+03	5.52E+03

Impact Assessment Results Beyond Building Life (per m^2)									
Building	Global Warming Potential (kg CO2 eq)	Acidification Potential (kg SO2 eq)	HH Particulate (kg PM2.5 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O3 eq)	Total Primary Energy (MJ)	Non-Renewable Energy (MJ)	Fossil Fuel Consumption (MJ)
AERL	5.81E+02	3.98E+00	2.25E+00	4.19E-01	1.77E-06	7.54E+01	1.73E+04	1.67E+04	6.91E+03
ALRD	3.38E+02	2.23E+00	1.18E+00	1.45E-01	1.64E-06	4.61E+01	7.29E+03	6.98E+03	2.85E+03
ANGU	3.76E+02	2.08E+00	9.46E-01	2.31E-01	2.53E-06	3.71E+01	4.27E+03	4.19E+03	3.64E+03
CEME	1.96E+02	1.19E+00	5.05E-01	1.72E-01	6.33E-07	2.49E+01	2.91E+03	2.79E+03	2.48E+03
CHBE	4.59E+02	2.93E+00	1.35E+00	1.70E-01	1.93E-06	6.20E+01	7.26E+03	6.92E+03	3.84E+03
CHEM	4.51E+02	2.72E+00	1.72E+00	6.21E-01	0.00E+00	5.78E+01	5.08E+03	4.81E+03	4.07E+03
CHEMN	4.98E+02	3.07E+00	1.15E+00	2.22E-01	2.53E-06	6.46E+01	5.37E+03	5.09E+03	4.58E+03
CHEMS	5.09E+02	3.12E+00	1.82E+00	2.99E-01	1.56E-06	6.47E+01	9.48E+03	9.09E+03	4.83E+03
CIRS	3.62E+02	2.93E+00	2.14E+00	2.66E-01	1.44E-06	5.76E+01	1.47E+04	1.40E+04	3.73E+03
ESB	3.29E+02	2.45E+00	2.00E+00	2.41E-01	1.11E-06	4.54E+01	1.41E+04	1.34E+04	3.02E+03
GEOG	7.16E+01	1.07E+00	3.55E-01	7.63E-01	5.75E-07	2.05E+01	5.46E+03	4.98E+03	4.92E+03
HEBB	3.64E+02	2.37E+00	8.50E-01	2.26E-01	1.36E-06	5.12E+01	4.16E+03	3.98E+03	3.69E+03
ICICS	8.42E+02	5.12E+00	2.28E+00	5.23E-01	3.64E-06	1.06E+02	1.06E+04	1.01E+04	7.87E+03
KAIS	3.35E+02	2.15E+00	1.52E+00	2.98E-01	1.11E-06	4.40E+01	7.82E+03	7.49E+03	2.91E+03
KENN	4.03E+02	2.36E+00	1.13E+00	2.36E-01	1.37E-06	4.79E+01	5.57E+03	5.33E+03	3.81E+03
LASR	3.93E+02	2.25E+00	1.08E+00	2.02E-01	0.00E+00	4.44E+01	4.70E+03	4.49E+03	3.79E+03
MATH	4.36E+01	7.66E-01	3.91E-01	4.40E-01	4.58E-07	1.76E+01	2.13E+03	1.79E+03	1.75E+03
MCML	6.76E+02	4.22E+00	1.47E+00	1.80E-01	2.83E-06	9.14E+01	7.76E+03	7.28E+03	5.59E+03
MUSC	2.68E+02	1.68E+00	6.99E-01	1.40E-01	9.33E-07	3.79E+01	3.15E+03	2.99E+03	2.59E+03
SCRF	3.16E+02	2.08E+00	7.28E-01	2.12E-01	1.51E-06	4.52E+01	3.64E+03	3.44E+03	3.24E+03
WESB	5.81E+02	3.87E+00	1.24E+00	2.44E-01	1.96E-06	8.12E+01	7.04E+03	6.75E+03	6.01E+03