Life Cycle Assessment at UBC Vancouver Campus

Ava Li, Joanne Chow, Matthew Yam

University of British Columbia

CIVL 498C

November 19, 2014

Life Cycle Assessment at UBC Vancouver Campus

CIVL 498C Project Final Report

Authors:

Joanne Chow (#

Ava Li (#

Matthew Yam (#

Prepared for: Penny Martyn, Rob Sianchuk & Raza Jaffery

November 19th, 2014

Executive Summary

Students from CIVL 498C course conducted a Life Cycle Assessment study on the academic buildings on the UBC Vancouver Campus. This study determined the environmental impacts from material use and construction of the buildings, which gave an opportunity for students to understand the changes needed to minimize the life cycle impacts of constructing buildings at UBC. To conduct the study and accompanied analysis, students used the Athena Environmental Impact Estimator tool.

Results from the study determined that in order to institutionalize LCA studies at UBC Vancouver Campus, guidelines and standards similar to those used in the course's LCA study must be set by the Campus and Community Planning Green Building Division. The LCA studies should also be marketed to encourage a healthy dialogue between stakeholders who will potentially request these studies.

Table of Contents

1.0 Introduction

Life cycle assessment (LCA) is a very powerful tool for assessing environmental impacts of products and services from cradle-to-grave. Using this tool, students in CIVL 498C at UBC have conducted a comprehensive and detailed study of the impacts of the academic buildings at the Vancouver campus, taking into account the raw material extraction to processing to disposal. The impact estimator used in the study is the Athena Impact Estimator for Buildings, which is consistent with the latest US EPA (Environmental Protection Agency) TRACI methodology, that stands for Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts.

UBC's goal is to rationalize the institution of environmental LCA in UBC building design and operations. This report will first present UBC's goals in sustainability and the current guidelines that UBC has established for building design and construction on campus, followed by the details of the study which include data and calculations of the assessment of UBC's existing buildings. Finally, the report will provide recommendations on how the school can implement LCA in the future developments. These topics will be covered in three main sections which answer the following questions:

1) Context of use of LCA at UBC: in which areas can LCA's applications support sustainability programs that affect buildings?

2) LCA study of academic buildings at UBC Vancouver Campus: what are the methods used in this year's CIVL 498C research course? What are the results and implications?

3) Next steps to institutionalizing at UBC: how should UBC approach the institution of LCA in building design and operations?

2.0 Context for use of LCA at UBC

In which areas can LCA's applications support sustainability programs that affect buildings?

2.1 Climate Action Plan (CAP)

The goal of implementing the CAP is to achieve a low carbon future through reducing emissions and reacting to climate change. UBC also hopes to form partnerships and become a local and global leader for future generations in tackling climate change. CAP even exceeds the minimum reporting requirements, and addresses topics such as travel, procurement, and food, which UBC is not currently responsible for ("UBC Vancouver Campus," 2014).

UBC currently reports its GHG emissions and progress updates annually in order to comply with the Greenhouse Gas Reductions Target Act (GHGRTA) for British Columbia. According to the Environmental Protection Agency (EPA), GHG includes carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and fluorinated gases (aka high global warming potential gases or high GWP gases) ("United States," 2014). The GHG are emitted primarily through the heavy use of energy, especially in research and operation facilities. UBC is exactly this – a research intensive institution – so in order to reduce the environmental impacts of GHG emissions, UBC has set a goal to develop strategies to implement the use of renewable energy sources in new and old buildings.

In this study, the products are the buildings at UBC. LCA assesses several types of emissions that result from the cradle-to-grave process: from resource and material extraction, to creation, and to disposal. One way that the CAP can utilize LCA is to incorporate life cycle inventory results when reporting GHG emission and progress updates annually. CAP currently covers emissions relating to travel, procurement, and food requirements, which goes beyond the minimum reporting requirements. LCI results for the buildings would fit under the procurement category, or perhaps create a new category on its own in the reports. Not only would presenting the data by LCA demonstrate leadership in reducing GHG, but it would also showcase and test the capabilities of this new and emerging tool.

2.2 Vancouver Campus Plan Part 3 Design Guidelines

The first category under the "Campus-Wide Design Guidelines" is sustainability, which takes into account of the social, economic and ecological considerations, Leadership in Environmental and Energy Design (LEED), sustainability best practice building design, and the UBC Climate Action Plan (CAP). Economic sustainability can be analyzed using LCA when selecting designs and materials that contributes to "cost-effective, durable, and low maintenance buildings and improvements" ("University of British," 2010). LCA gives the user and opportunity to design elements (such as change the dimensions) and choose the material properties (such as concrete, steel, and wood). The user can test different combinations using this tool and find a suitable design that meets the minimum criteria as defined by the CAP or other building or environmental regulations. LCA is a great tool to analyze the consequences of different design and material selection strategies. As for the social considerations, LCA currently does not address social impacts. However, researchers and developers of environmental assessment tools do hope to introduce health indicators in the future. This would introduce new challenges and opportunities for improving the current systems.

In terms of achieving energy efficiency on campus, UBC has a set of sustainable building guidelines for planners and designers to consider in the early stages of the project to design for LEED requirements and to better the building's performance. The guidelines emphasize on several physical aspects such as:

- Orientation
- Shape and massing
- Windows and glazing
- Thermal mass
- Durability
- Resource efficiency

The above factors contribute to the overall space planning for buildings. For example, selecting heavier building materials such as stone and concrete which have high thermal mass and the capability to retain heat energy would increase energy efficiency. Material selection is also important when measuring durability – UBC hopes to design buildings and building elements that have a maximized lifespan, and at the same time be reused and recycled. Since UBC takes energy efficiency very seriously, LCA may be able to contribute to the process of testing and selecting of materials by evaluating an impact category based on energy. The user would have the ability to test and produce impact assessments using different materials based on a service life that the user sets. To assess this impact, weather statistics could be incorporated into the impact estimator to compute the efficiency in terms of the material's heat energy retention and release in different seasons. The current LCA process considers only a cradle-to-grave profile that produces results that demonstrate energy and raw material flows and emissions. To take into account the energy efficiency of a building across its service life would definitely be a new challenge, but it should be considered when designing for UBC since a key concern highlighted in the Vancouver Campus Plan Part 3 is energy efficiency in buildings.

2.3 Technical Guidelines

2.3.1 Sustainability

In both the Climate Action Plan (CAP) and the Vancouver Campus Plan Part 3 Design Guidelines, material selection is a very important topic. UBC aims to optimize the use of materials that minimize environmental impacts. As mentioned in the previous sections, impact assessment estimators can definitely help the user during the material selection process. However, in order to assess different material types and combinations, a large database of materials must be made available. This database must also be updated regularly using EPD's. The more specific the material properties are in the database, the more accurate the results will be and the bigger the variety of material combinations to design with. Generating this database would be a good upgrade for LCA implementation for places like UBC to use in their technical guidelines that relate the use of materials to sustainability.

2.3.2 Life Cycle Costing Toolkit

During the design stage of a building, designers complete a life cycle cost (LCC) analysis using the triple bottom line approach which focuses on UBC's goal of sustainability; this approach emphasizes on economy, society, and ecology ("UBC Technical Guidelines," 2014). A toolkit has been developed which covers common design parameters that are also applied to an LCA analysis (See **Appendix D**). Examples of these parameters include life expectancy and CO2 emissions.

There are several differences and similarities between LCC and LCA. LCC analyzes the direct monetary values and costs relating to the product (in this case, the building), and covers categories such as operating cost, maintenance cost, salvage value, and total net present value (the economic baseline). It also takes into consideration the aesthetics and safety of operation (the societal baseline), recycled content, and indoor air quality (the ecological baseline). On the other hand, LCA assesses the environmental impacts. They are two separate and unique life cycle approaches and unfamiliar users are often confused.

This raises a good discussion for future improvements or implementation of costing into the impact estimator software. There are three pillars of sustainability: environmental, economic, and social. LCA currently encompasses the environmental aspect only – is there capacity to achieve more and evaluate the economic and social impacts? Incorporating economic models and sociocultural development could possibly be the next step in redefining the use between LCC and LCA. Perhaps in the future there would be a software that could assess costs and environmental and health impacts simultaneously as it is evident that these topics affect decisions when designing for sustainability. This tool would be very useful for UBC during the building design stage in achieving the school's core vision of sustainability.

2.3.3 Performance Objectives

The primary objectives of the UBC Technical Guidelines summarize most of the topics that have been mentioned in the previous sections concerning sustainable design (reducing GHG emissions, reducing energy consumption, focusing on material selection, etc.). One objective that has not been discussed yet is UBC's goal to demonstrate innovation and research application in sustainability and design ("Performance Objectives," 2014). UBC is a research intensive institution and has a lot of potential for innovation and product development. The school's initiative in establishing sustainable design guidelines and becoming a net positive energy producer by 2050 opens up a great opportunity for researching about climate change and the environmental impacts relating to the life cycle of the buildings on campus. CIVL 498C is an excellent opportunity to start this research process. Utilizing the impact estimator, students could obtain a bill of materials and evaluate impacts in several categories such as global warming potential and ozone depletion. Both the course and the software are relatively new; therefore, there is definitely room for improvement and development. An idea to consider for future research recommendations is to generate building and material databases that takes into account all the buildings on campus, or even all the buildings in Vancouver. This could ultimately initiate more publications of EPD's locally, and help UBC and the city of Vancouver reach their goal of becoming one of the greenest communities on earth.

2.3.4 The Metrics of Sustainable Buildings

Christoph Osphelt has written an article about the origin of LCA, its framework, and evaluates its limitations and effectiveness in present-day applications. He discusses the importance of taking into account upstream processes when examining a building's life cycle from cradle to grave. It has been observed that the upstream processes such as the transportation, production, and manufacturing building materials consume nearly the same amount of energy as the operation of a building throughout its service life (Osphelt). Many users are oblivious to these upstream processes as these are often viewed as less significant when compared to the physical amounts of emissions and energy consumed during the operation of a building. Upstream processes are indirectly related to the building’s sustainability and are more difficult to measure. However, to increase the environmental effectiveness of products and services, the designer must take a step back and look at the bigger picture which captures these processes that define a building’s life cycle.

Another important step that designers and users often overlook is the comparison between costs incurred during the design and construction stages, and the costs that are paid later when the building is in the operation stage. It has been observed that in many case studies, paying extra at the early stages for the construction of an airtight and insulated building envelope is acceptable compared to a building that meets the minimal requirements which would result in long-term costs of damaging the environment. With a database that consists of innovative and green building materials and elements (such as high performance windows), users practicing LCA would gain a better understanding of the cost-effectiveness in implementing high-tech components and relate the assessment results to the environmental consequences in the long run.

One common flaw of LCA strategies is the uncertainty and the trade-off between technical accuracy and objectivity. The more inventories, databases, and scientific processes involved in producing an assessment, the higher the error margin. Impact estimators also act like black boxes – parameters are input by the user which generates the assessment results without “showing work”. It becomes difficult for the user to understand how the results are derived which then creates a knowledge gap. Furthermore, the more tools and methods there are, the bigger the range of characterization factors for the same impact categories. These are defined by priorities set by the developers by region (i.e. TRACI in North America would have different characterization factors compared to GaBi which is used in Germany). The weights that are used to prioritize the categories are based on a mix of expert opinions and scientific proof; thus increases the level of uncertainty. The data behind some impact categories are also underdeveloped; in order to minimize the trade-off between accuracy and objectivity, LCA parameters such as the impacts and indicators should be updated periodically.

2.4 UBC RFI Evaluation Criteria (See Appendix E)

From the RFI document, it is evident that UBC values sustainability in the design and construction of new buildings as well as in the renovations and renewals of old buildings. The RFI requires qualified firms to submit proposals that follow sustainability objectives and principles by optimizing space, determining the most cost-effective life cycle costs, and meeting building codes and standards. Under the evaluation criteria for the proposals, the following strategy/criteria each have a 5.0 rating (out of a total of 100.00):

- An innovative, holistic, integrated methodology and work plan will be needed: a clear, systematic methodology for developing the Project Plan, including life cycle assessment of project options and their costs

- An effective, multi-discipline team is needed: include life cycle assessment of project options

The ratings of the two categories sum to 10.0, which is 10% of the total criteria. Most of the remaining criteria have a 5.0 rating as well, which demonstrates the importance UBC sees in the integration of sustainability into building design. It also specifically states to include the life cycle assessment of different project options and their costs (LCA and LCC), and recommends to have a team with a member who is familiar or even better, an expert, in LCA strategies and implementation. UBC is stepping up as a leader in adapting and responding to climate change. The planning team values environmental and human health effects, and strives to achieve high sustainability standards. In order to meet these expectations, firms must also upgrade resources and find expertise in assessing environmental impacts.

2.5 LEED v4

Starting in 2008, achieving LEED Gold certification is mandatory for all provincially funded/publically owned projects in BC (whether it is new or categorized as a major renovation) that are greater than 600 m^2 (“LEED @ UBC,” 2014). Under the LEED v4 building life-cycle impact reduction category, up to five points can be awarded (U.S.

Green Building Council, 2014). There are four options, one being a “whole building life cycle assessment” (See **Appendix B - Figure 7**). A minimum decrease of 10% in three of the six specified impact categories must be achieved, one of which is the global warming potential. In addition, impact categories cannot increase by more than 5%. These percentages are calculated with respect to the baseline building. In Stage 2 of our project, we modified parameters using the Athena impact estimator such that the assigned buildings would be awarded three points in this option. It was fairly easy to achieve the three points when modifying newer buildings such as the Henry Angus building and the Fred Kaiser building. It was much more difficult to do so for older buildings such as the Wesbrook building. The results of Stage 2 will be discussed in more detail in the next section of this report.

Currently, the “whole building LCA” is an option in LEED v4 and there are discussions and debates on whether to make this option mandatory. As a team of research students who are studying the LCA strategies, it can be recommended that it remain as an option today, based on the fact that the development of LCA is still relatively new and there is room for growth in terms of increasing scientific accuracy behind databases and indicators. The tool is being introduced to designers and consultants and is slowly gaining popularity as it is an option under the LEED v4. Forecasting into the future, it is highly likely that the application of LCA will become a mandatory category under LEED. This is because impact estimators are becoming increasingly advanced and reliable. We develop and rely on computer software which is much faster, more efficient, and somewhat reliable. As more information and research data are collected, the more complicated and sophisticated the tool will become. However, we should always keep in mind that for designers to integrate such tools into planning and design, tools must maintain simplicity, credibility, and transparency.

3.0 LCA Study of Academic Buildings at UBC (Vancouver)

3.1 Methods

3.1.1 CIVL 498C Student Project – Background, Goal and Scope

Starting in the 2008/2009 academic year, UBC has introduced a pilot course – CIVL 498C – Life Cycle Analysis – to carry out Life Cycle Analysis on the university's buildings. This is the first course at UBC devoted to teaching the environmental impact assessment method of LCA.

In previous years, students used structural and architectural drawings combined with site visits to create profiles for the different elements and materials of their specific building. The profiles created were used to generate whole building LCA models using the Athena Environmental Impact Estimator. The Impact Estimator used in the earlier years of the course was underdeveloped and since had improvements and updates made to the program. Using the previous version of the Impact Estimator, each building had results generated for based on seven impact categories:

- Fossil Fuel Consumption
- Global Warming Potential
- Human Health Respiratory Effects
- Eutrophication Potential
- Ozone Depletion Potential
- Acidification Potential
- Smog Potential

Each LCA also included a Bill of Materials, Life Cycle Inventory (LCI), as well as a Life Cycle Inventory Assessment (LCIA).

The main deliverable for students is to create a record of material inventories and environmental impact references for the buildings at UBC for potential future use in the construction of new buildings and the upgrades of old buildings. As LCA is applied to more and more buildings across the UBC campus, comparisons can be made over time between different structural types, building materials, use of the building, and the various environmental impacts.

This year, each student in CIVL 498C has been assigned an academic building at UBC. The following twenty-four buildings were analyzed as part of the multi-year LCA study on UBC buildings:

- Hennings Building
- HR MacMillan Building
- Institute for Computing, Information and Cognitive Systems
- Centre for Interactive Research on Sustainability
- Neville Scarfe Building
- Hebb Building
- Chemistry North Wing
- Wesbrook Building
- Henry Angus Building
- Geography Building
- Chemistry South Wing
- Earth Sciences Building
- Allard Hall
- Math Building
- Civil and Mechanical Engineering Building
- Forest Sciences Centre
- Music Building
- Chemical and Biological Engineering Building
- Frederic Lasserre Building
- Pharmaceutical Sciences Building
- Fred Kaiser Building
- Douglas Kenny Building
- Aquatic Ecosystems Research Laboratory

The students used the existing LCA models created in previous years and modified the model such that the Impact Estimator analyzes the buildings over a life span of sixty years. For each of the UBC buildings, new reports for the Bill of Materials and Impact Categories were generated using the new version of the Impact Estimator and imported into a Google Document spreadsheet where the total effects for the various assemblies and materials was compiled. The buildings had results generated for the following nine Impact Categories:

- Global Warming Potential
- Acidification Potential

- HH Particulate
- Eutrophication Potential
- Ozone Depletion Potential
- Smog Potential
- Total Primary Energy
- Non-Renewable Energy
- Fossil Fuel Consumption

Subsequently, the students used the entire class' results to compute a benchmark of all building impact assessment results and total material mass for whole building for each respective element. Using this benchmark, students awarded LEED points to their assigned building according to the LEED documentation "Building life-cycle impact reduction – Option 4" (See **Appendix B - Figure 7**).

Each building's LCA model was then modified by changing parameters such as the material selection and the assembly type in the Impact Estimator to achieve three LEED points in comparison to the pre-modified building in accordance with the previously mentioned LEED document. This allowed students to quantitatively understand the magnitude of changes required for LEED standards.

3.1.2 Uncertainties

The LCA study can be conducted efficiently using an Impact Estimator. But with any estimating and analysis tool, there are uncertainties within the data and the subject of reliability often becomes a topic of discussion. The following describes the uncertainties in the CIVL 498C 2014 Database as well as the databases of LCA tools.

The benchmark used for determining the number of LEED points awarded was computed using multiple sets of data generated by the entire class; there are many concerns regarding the reliability of the data. One such concern is that each building was analyzed by a different student and therefore may consist of human errors while working with the Impact Estimator or importing of data into the group Excel document. In addition, the class database was developed based on results and studies conducted by previous CIVL 498C classes; their results obtained may hold uncertainties and inaccuracies as well. Many buildings assigned had information missing in various elements which affect the Impact Categories' results. Missing information from last year's results has been updated this year to complete the database.

There are also several buildings that were missing data or had incorrect data and are excluded from the final part of the analysis, such as the Hennings Building and the Pharmaceutical Sciences Building. Also, some students have excluded the Douglas Kenny Building, Geography Building, and Frederic Lassarre building when computing the benchmark or the nine Impact Categories; this has yielded incomplete data. Each student in the CIVL 498C class was assigned a specific building for analysis. Since the individual Impact Estimator Models were made only available to the assigned student, it was very difficult to correct the benchmark data.

Another concern regarding the completeness of this year's database is that the Impact Estimator that was used to conduct the LCA study is based on the Athena LCI database. The ALCI database has material information that is up to date. Many of UBC's buildings such as the Chemistry Building (built in 1961), Hebb Building (built in 1964), and H.R. MacMillan Building (built in 1967) are more than forty years old. The use of the present, newer information on materials on older buildings will cause inaccuracies in determining the emissions for each Impact Category. Also, the Bill of Materials generated in the Impact Estimator only accounts for the amount of a specific material delivered on site. It does not account for the extra materials ordered and transported to and off site during construction.

The Characterization Factors used in estimating models may not reflect the actual weight of the environmental effects. For any category or effect that has yet to be researched, the Characterization Factor is zero. This shows that if the category of the LCI database has no previous knowledge, its effects and damages on human health will not be incorporated into the study. This will affect the accuracy of the LCA study as it does not reflect the reality of the building's effects on the environment.

3.2 Results

A total of 1,207,560 tonnes of eighty-seven different materials were used in constructing the twenty-four buildings of UBC. A pie chart shown in **Appendix B - Figure 1** shows the quantity of each material used in comparison to the complete list of materials. The material that had the highest used massed quantity is the ballast (aggregate stone) with a total of 550,992 tonnes, totalling 46%of the total material mass. This is reasonable as many of the buildings were constructed using high amounts of concrete. Concrete has a mass totalling to 240,009 tonnes.

After comparing the nine Impact Categories shown from **Appendix B - Figure 2 to Figure 4**, it is evident that the Hennings Building has the highest impact on the environment. In contrast, the Forest Sciences Building consistently has the least impact on the environment.

3.3 Discussion

3.3.1 Designing Buildings that Minimize Environmental Impacts

Using the two buildings that exhibit the highest and lowest environmental impact, it is easy to see which materials should be used for future construction or upgrades of the buildings at UBC. **Appendix B - Figure 5** shows the material composition for the Hennings Building. It shows that approximately 37% of the building is composed of 20 MPa concrete mixed with fly ash. In addition, 29% of the building comprises of precast concrete and 16% of the building is constructed using 30 MPa concrete mixed with fly ash. This yields a total of over 60% of concrete in the entire building. For the material composition of the Forest Sciences Building, **Appendix B - Figure 6** shows that 61% of the structure is composed of ballast, a type of aggregate. After further research, it has been determined that the ballast was used to construct the roof. A layer of ballast may have been used to install large sheets of roof membrane during the construction process. The Forest Sciences Building is also made mostly of wood and water-based materials such as kiln-dried softwood lumber, softwood plywood, and water based latex paint. The total concrete in the building only totaled to approximately 6% of the entire building.

These results demonstrate which materials would cause the least environmental impact when constructing structures at UBC. Wood and water-based products should be used for the walls and supporting elements when possible, whereas concrete and concrete products should be used minimally.

3.3.2 Use of Previous Models to Achieve LEED Points/Sustainability Program Support

In order to achieve the previously mentioned points from the LEED document, students modified the materials in the files of the assigned building's previous models while using the original building models as the benchmark.

As foundations in a building are the basis of support for the whole structure, little could be done to change the use of concrete to another material for the Foundations Element (A11). In the Upper Floor Construction Element (A22), students replaced concrete beams and columns with glulam wood. In addition, in place stairs with load bearing wood studs were casted instead of using the aluminum studs. In the Roof Construction Element (A23), concrete beams were also placed with glulam to reduce the concrete composition in the whole building. In place exterior walls for Walls Below and Above Grade (A31 and A32) were replaced with wood stud load bearing walls to also reduce the use of concrete in the structure.

Students also found that when concrete was necessary for construction, increasing the fly ash content will also lower the impact on the environment. As fly ash does not affect the strength of the concrete, it can be used to replace 25% - 30% of cement in the concrete mixture. Fly ash costs less than cement and could help with the economic aspect of the construction project.

4.0 Next Steps for Institutionalizing LCA at UBC (Vancouver)

In order to incorporate LCA studies in all UBC building design and operation decision making processes, the institution should focus on creating interest and increasing the demand for such studies. This can be successfully achieved through promoting existing LCA studies on UBC buildings and facilitating the understanding of the studies by educating the general community about LCA. The studies also need to be properly marketed to encourage people to take initiative and ask for the right information from LCA studies. In addition, requirements should be set to ensure that certain baselines are met for specific categories in a LCA study, similar to that for LEED Gold certification for all new building projects at UBC.

Most people would describe LCA as the accounting of resources used in a product's or system's life cycle from cradle-to-grave. However there is a lot more to conducting a LCA study than just material accounting. System boundaries, impact categories, and the product systems are just a few of the main components that influence the outcome of the studies and need to be defined accordingly. The many components and their complex interactions can be organized using LCA Modelling Tools, LCA Databases, and LCA Decision Making Methods, which help summarize the information from a LCA study effectively. In order to make use of the results from the studies, it is important to distribute the findings accordingly through the use of adequate LCA Communication and Education Resources. Hence there are four main tools for LCA to be successfully institutionalized at UBC: Modelling Tools, Databases, Decision Making Methods, and Communication and Education Resources. All four methods must be properly developed for a seamless integration of LCA studies in building projects at UBC.

4.1 LCA Modelling Tools

LCA is a complex methodology that involves many variables and does not define one thing that points towards a "green" absolute. Therefore, a wide range of modelling tools is available for LCA studies to help assemble information about the variables and produce more manageable results that can better communicate the environmental impacts.

The tools available for LCA studies can be classified in the three basic levels according to a framework developed by the Athena Institute. These help the community compare systems and help determine what they need to use for their purpose of the study (Trusty, 2001). The following is a summary of each level of the classification framework (Trusty and Horse, 2005):

> **Level 1 –** Utilized in the Life Cycle Inventory Analysis stage. It focuses on individual products or assemblies and involves the input and outputs of unit processes for a particular product system. It quantifies category impacts of the product to make comparisons in environmental or economic criteria, such as Global Warming Potential or Smog Potential, etc. Examples include SimaPro, GaBi, BIRDS, and BEES.
>
> **Level 2 –** Utilized in the Life Cycle Impact Assessment stage. It focuses on complete building assemblies, elements or whole buildings. It draws from the results from Level 1 and generates category impact information based on the design of the building components being considered. Examples include Athena Environmental Impact Estimator, BRI LCA, and LISA. Level 2 Tools can also incorporate operational values such as energy consumption in its assessments.
>
> **Level 3 –** Focused on whole building systems and includes a broad range of environmental, economic, and social aspects. It is used to guide or inform the design process. Examples include BREEAM, GBTool, and Green Globes. (LEED can also be classified in this category.)

The growing use of 3D CAD and Building Information Modelling (BIM) in today's construction industry have prompted the development of sophisticated tools such as Tally & Revit, LCADesign, AutoDesk Ecotect, and eToolLCD to be integrated with the building model and yield immediate results in response to design changes. These tools make it easier for designers and engineers to consider environmental impacts early in the design process, where most of the major design decisions impact the life cycle of the building the greatest.

In the context of LCA at UBC, the best tools to focus on would be those in the Level 2 category (such as the Athena EIE). Each tool also varies between different regions, and therefore tools that use databases that best represent UBC's goal and scope will provide the best indication of environmental impacts. It is also important to note that each tool is not in competition and can complement each other. It is recommended that a standardized modelling tool that uses a set functional unit for each relevant impact category be used at UBC to ensure fair comparison between the buildings.

4.2 LCA Databases

In conjunction with LCA modelling tools, the databases which the tools help build and retrieve inventory data should be standardized and specific to the materials and construction practices used at UBC. TRACI from the Environmental Protection Agency is a midpoint model for building LCA databases that incorporates the following impact categories:

- Ozone Depletion
- Global Warming
- Acidification
- Human Health Cancer
- Human Health Non-cancer
- Human Health Criteria
- Eutrophication
- Smog Formation
- Eco-toxicity
- Fossil Fuel Use
- Land Use
- Water Use

Depending on future needs at UBC, endpoint models which provide a damage assessment on the natural environment, human health, or resources, can be used instead of a midpoint model. Midpoint models focus mainly on emissions and potential impacts prior to the endpoint and include characterization factors that reflect the relative importance of an impact category (Bare et al., 2000). However, it is unlikely to forecast what will happen based on the midpoint model impact categories. This is why the midpoint model is good at representing the amount and importance relative to each category and is effective at helping designers make an informed decision on which impact categories they want to focus on minimizing. Endpoint models would be more suited at conveying environmental and health impacts to the community.

4.3 LCA Decision Making Methods

A LCA needs a plan to become useful in helping designers make meaningful decisions early in the building project. The results that come out of a LCA must be compared to a certain reference point for it to hold any meaning. This is where setting a baseline becomes useful. The baseline can be any level of a particular impact category that UBC is trying to achieve. This goal can be predetermined and required for all new building projects or renovations, similar to the LEED Gold standard in the present buildings. The results from LCA studies can then be complimented with impact aversion surveys and financial-environmental analysis to help designers come to a decision on what needs to be focused on to improve the environmental footprint of the building being constructed.

To figure out a reasonable value for these baseline studies, LCA studies can be conducted retroactively to determine their values and set a guideline of improvements based on the averages from the studies for each impact. There is a guideline that is already available in LEED v4 that awards up to three points for whole building life cycle assessments in the building life-cycle impact reduction section (See **Appendix B - Figure 7**). However the guideline set by LEED does not explicitly control the requirements for the baseline used in the study. The problem with this is, in practice, a lot of designers produce an alternative scheme that performs worse to have an easy baseline to gain LEED points from. This can be avoided at UBC by setting a standard throughout the campus and having the baseline predetermined by the institute rather than the designer. This also gives UBC the opportunity to customize the focus of the impact categories to those that are seen more favourable for the institution.

4.4 LCA Communication and Education Resources

The most important aspect to institutionalizing LCA at UBC is finding the appropriate medium to communicate to the various stakeholders the findings from the studies.

Marketing LCA effectively at UBC will prompt discussion of the topic to spread and thus encourage a higher demand for LCA studies as people take initiative to ask for information about the environmental impacts relating to the buildings on UBC.

The best way in approaching this task is to improve the understanding of LCA for the stakeholders of UBC. LCA studies that have already been conducted can be used to educate people on how certain design decisions can have a profound impact on the environment. The history of existing buildings and their environmental impacts according to LCA studies can be emphasized at presentations and current related courses at UBC. Furthermore, additional classes and workshops can be set up for those who show deeper interest in the subject matter. LEED has already been successfully publicized at UBC and LCA can use the LEED building initiative to promote itself and raise awareness on the benefits of LCA studies.

To institutionalize LCA studies at UBC, it is recommended that a proprietary set of guidelines be established based on TRACI; these can be tailored to build UBC's own inventory database. The existing buildings on UBC should then be analysed using a specified tool (which can change depending on technological advances) and the information collected in UBC's inventory database. A similar process to the LCA study that was done as part of this course can help develop a database, and a baseline that is specifically for UBC can be used to design and construct new buildings in the future.

The design decision process for environmental impacts at UBC will become more efficient once it is able to set the standards for LCA modelling tools, database guidelines, and the baseline values. This will enable UBC to provide LCA information when needed and can therefore showcase the environmental-cost benefits of having LCA studies early on in the design process.

5.0 Conclusion

After conducting a detailed study using Athena's Impact Estimator on UBC's buildings, the students determined the impacts that stemmed from the procurement and construction of buildings on the UBC Vancouver campus. Focusing on how UBC can integrate LCA into building design and operations, the report provides recommendations on establishing guidelines for UBC to begin institutionalizing LCA in developments.

UBC currently uses five documents to guide the institution into becoming a sustainable university. LCA is used to support some of these documents to showcase the capabilities of this fairly new tool. It was discussed that LEED v4 had specifically incorporated six impact categories from the impact estimator and was used as a criteria to award points for construction of new buildings as well as renovations to existing buildings.

Using the Athena Impact Estimator, twenty-four of UBC's academic buildings were analyzed and it has been concluded that replacing concrete components with wood would significantly reduce the impacts the building had on the environment. When concrete is used for construction, increasing the fly ash content will lower the impact on the environment. Although there are many uncertainties with the database used, it shows that buildings that were constructed in the earlier years cause more impact than buildings constructed recently.

It is recommended that a set of guiding principles be developed at UBC to aid in institutionalizing LCA; the principles shall be based on TRACI guidelines and be specifically for UBC's use. This will encourage UBC to build its own inventory database and create a baseline for development of new buildings in the upcoming years. "In the end, however much we do to make LCA useful, it will not really help unless the world believes that it is useful" (Jensen et al., 1997, p. 11).

Appendix A: Author Reflections

Author Reflection – Joanne Chow (#25668104)

Discussion of your previous exposure/experience with sustainability and LCA, and a brief overview of the topics covered in the course.

I did not have any previous exposure/experiences with LCA, but I did learn about sustainability in past courses (i.e. CIVL 305 – Environmental Impact Studies). I started the courses with no general knowledge of what LCA is and what tools are involved, but I hope to pursue a career in the building industry, which is why I picked CIVL 498C as an elective. This course is a research course (I have never taken a research course before) and topics covered include: what is LCA, why people use LCA and how it was developed, the terminology associated with LCA and ISO 14044, the retrieval of data from the impact estimator, and how LCA can benefit the future designs of the academic buildings at UBC.

Brief overview of what interested you about this course and the final project LCA study.

The part that interested me the most in this course was how LCA can be applied to UBC. As a student at the school, I find it very relatable to research and complete a project based on the buildings that I use every day on campus. This topic becomes even more interesting for me because I have work experience in the building and development industry, and I aim to work in this industry when I graduate. It is evident that sustainability is very important at a global level and researchers and scientists are trying to address this issue; LCA is a tool that can definitely help us in designing buildings that create positive environmental impacts. I also find that Stage 3 (the final project) is the most useful activity in the course. Students are equipped with sufficient knowledge of LCA and can finally relate LCA to designing academic buildings, and make connections to the building guidelines at UBC. Stage 3 allows students to apply what they have learned in the past three months; it is a great way to wrap up the course.

Write down any special interests or thoughts that you've had during this project.

One question that I have always wondered about since the beginning of the course is: other than environmental impacts, to what extent can LCA (or other similar tools) cover? For example, should we expect LCA to incorporate impact categories relating to social and economic factors? I believe that eventually, LCA would integrate these two factors into the studies in order to cover the three pillars of sustainability. After all, our ultimate goal is to achieve sustainability and perhaps LCA can address all three categories in the future!

Mark and briefly comment on which of the 12 CEAB graduate attributes you believe you had to demonstrate during your CIVL498C experience.

	Graduate Attribute			By: Joanne Chow (#25668104)
	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.	ID = introduced & developed	Personally, I lacked a lot of the background knowledge about LCA at the start of the course. I did not know much about it, but I was interested in the subject. The course did not involve mathematics, natural sciences, but did require students to have some knowledge about engineering, designing, and constructing buildings. This course helped me develop a better understand of how engineering (buildings) can impact the environment; I also learned more about the procurement, design, and construction of buildings.

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.	D = developed	Problem analysis was emphasized in the following areas: the airplane in-class activity and Stage 1/2/3. The airplane activity was a great analogy for students to follow and learn from before applying it to Stages 1/2/3. For the Stages and assignments, I had to play around with the Athena Impact Estimator and tried out different values for a variety of parameters and building components. Through these assignments I had the opportunity to see exactly what design factors created the most/least impact on the environment.
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	At the beginning of the course, students were asked to read 16 articles and write about 5 of them. This assignment had students investigate issues, limitations, opinions, and expectations of LCA. Not only did we have to summarize and write about our own thoughts and ideas, we had to do additional research for discussion purposes.

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.	ID = introduced & developed	The only design that students had to do for this course is through changing the values/parameters in the impact estimator to meet the LEED v4 requirements. There wasn't a significant design component in this course and we didn't get feedback on whether the proposed changes in the elements (in Stage 2) were appropriate or not. It would have been a good experience to actually design a new building for UBC.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	ID = introduced & developed	New engineering tools introduced to students were the Athena Impact Estimator. Professor Sianchuk and Raza also briefly mentioned other tools such as Tally, GaBi, SimaPro, etc. The course material heavily relied on the use of Excel in assignments. During Stages 1/2/3 when students played around with the impact estimator, it was evident that there were limitations and uncertainties of the tool (i.e. it is black box and the user cannot see how the inputs are transformed into output data). All in all, students worked a lot with the tool; it would have been easier for the students to learn how to use it if there was an in-class tutorial on how to use it before Stages 1/2/3.

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	Individual and team work were exercised in <u>all</u> assignments and in-class activities.
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	Communication is critical when it comes to working individually and in teams. Having to meet only once a week, communication between students and the professor via email was very important. There were many instances where the description/instructions for assignments were unclear and ambiguous; it took a lot of emails back and forth between the students and the professor to make sure that everyone was on the same page. Writing the final report also puts students to the test as students need to communicate to the audience the proposed ideas; the report needs to be written in a way that people who are not familiar with LCA understands the content and discussions.
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.	D = developed	Professionalism was practiced in Stage 3 - we have to write the report keeping in mind that the audience is Penny and people who may not be very familiar with the context of LCA. The report has to be written and presented in a concise and clear manner, using the correct terminology learned in the course. In addition, guest speakers also preached the class on professionalism when introducing their work and projects.

9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	IDA = introduced, developed & applied	This is the main focus of the course. The Athena Impact Estimator assesses the impacts of engineering (procurement of materials, construction of the building, and disposal of the building after its service life) on society and the environment based on several impact categories (ozone depletion, global warming, acid rain potential, etc.). During in-class activities and through assignments, students were prompted to think about how the use of LCA on buildings can support our society in the environmental aspect, as well as the economic, social, health, safety, legal, and cultrual aspects. Personally, I find that the course curriculum meets the expectations of this attribute the most, and the material was straightforward for students to understand.
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	N/A = not applicable	We did not discuss ethics and equity in this course.
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	Professor Sianchuk and other guest speakers presented their work to the class throughout the semester. They gave examples of the projects they worked/are currently working on. They also explained the expectations of their profession, how they can contribute to the application of LCA, and their thoughts on how LCA can influence buildings in the future.

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.	I = introduced	This topic wasn't emphasized very much in class. However, Professor Sianchuk did explain that the application of LCA is fairly new in this world, and that there are endless ways to improve the tool so that it is more accurate and covers even more impact categories in the future. Learning and developing LCA is a life-long learning process, especially when almost everything depends on technological advancements nowadays.

Author Reflection – Ava Li (#44623106)

Discussion of your previous exposure/experience with sustainability and LCA, and a brief overview of the topics covered in the course.

I did not have any previous exposure or experience with LCA prior to entering the course. I did, however, have learned about sustainability in many courses throughout my undergraduate degree. Sustainability was emphasized in first year in the course APSC 150 – Engineering Case Studies, as well as in our fourth year course CIVL 305 – Environmental Impact Studies.

There are several topics incorporated into the syllabus of the course, but there are a few that build the foundation of the LCA studies and what we learned. As this course is a research course – with a research paper as the end-of-term project – we learned about the history of LCA and how it was developed to what it is today. In addition, we had learned about what LCA actually is and the various terminologies incorporated into the studies. Most importantly, we discussed how LCA is incorporated into LEED for obtaining points as well as how LCA can be applied for existing and future buildings of UBC.

Brief overview of what interested you about this course and the final project LCA study.

Prior to entering CIVL 498C, I was working for a company that commercializes hydrokinetic turbines. As their goal was to be “environmentally friendly” with various aspects of the product, I began looking into different studies and ways to assess the “eco-friendliness” of the turbine. During this time, I had also begun to look into my technical electives for my upcoming fourth year of Civil Engineering. CIVL 498C was one of the electives and coincidently was about life cycle analysis of products. Although the course was focused primarily on UBC’s buildings, I could apply this knowledge to my company's products as well. Learning about LCA's cradle-to-grave or cradle-to-cradle schemes allows me to incorporate these ideas into future projects and products.

The final project uses the student's knowledge of LCA to analyze and relate how UBC can use LCA studies to further contribute to UBC's goal of being a sustainable university. As students now have the knowledge and ability to apply LCA concepts to buildings and projects, we are able to relate how using LCA can help UBC in constructing more sustainable structures. Stage 3 of the final report was the most interesting as it had students conduct research and analyze data using the skills they've acquired in the past three months.

Write down any special interests or thoughts that you've had during this project.

I've always wondered how reliable the data in each LCI is. For example, each IE has their LCI according to the company that has developed the program. If the companies from different countries were to all develop one IE for one specific country, would all the data be the same? Or would there be differences according to how they collect data. If there are discrepancies, then how do we know the LCI is reliable?

Mark and briefly comment on which of the 12 CEAB graduate attributes you believe you had to demonstrate during your CIVL498C experience.

	Graduate Attribute			By: Ava Li (#44623106)
	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.	ID = introduced & developed	My background knowledge for LCA was very minimal at the beginning. During the course, I was introduced to the concept of LCA and have since then developed a basis for the study. The course didn't require any mathematics or natural sciences but did incorporate engineering fundamentals such as knowing parts of a building or the construction process of a building. Through this course, I was able to learn more about how engineering can impact the environment and what processes can contribute more than others.

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	Problem analysis was used throughout the course in various areas. Homework assignments as well as Stage 1, 2 and 3 all required problem analysis skills. I was also able to apply problem analysis skills while using the Impact Estimator when I was able to play around with the program and try to lower emissions from different materials during the final project.
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.	ID = introduced & developed	During the semester, students were encouraged to do additional research for topics they had questions about. Our first assignment required us to read 16 articles and investigate for further developments in the LCA industry. I was introduced to the LCA concept this semester and throughout the semester I was able to develop more research and investigation skills.

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.	ID = introduced & developed	For this course, the design work included changing various materials in buildings to design for a low-emissions structure. We were given the task of changing the parameters to meet LEED v4 requirements. There wasn't much design work incorporated into the course but would be a great addition to design or modify extensively an existing building to the following year's syllabus.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	ID = introduced & developed	The Athena Impact Estimator was a tool that the entire class had learned to use for various components of the final project as well as for class assignments. There were other tools introduced to us that could be used for LCA analysis such as GaBi and SimaPro. This course was relied heavily on the AIE as we had to use this for most of the final project. Learning to use this program also provided a deeper understanding of the LCA analysis.

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	All assignments and projects required teamwork as well as individual work. The final project had two parts that was individual work and the last part being a group research project.
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	DA = developed & applied	Communication is essential for all aspects of engineering. This skill was exercised during all team-based work as well as in class with Professor Sianchuk. As this class only met once a week for three hours each time, the communication between student and professor was critical. E-mail communication was the primary communication tool between students and the professor. As there were many instances where assignments and tasks were unclear, there were many e-mails sent back and forth regarding clarifications.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of	D = developed	Professionalism was developed through the whole course as the final research paper was primarily for an audience with very little technical knowledge of LCA. As this was a research paper, many topics had to be explained in an understandable manner. Professor

		the public and the public interest.		Sianchuk and other guest lecturers also spoke of being professional in their work and projects with clients.
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	This course was aimed to assess the impacts of engineering on society and the environment. Using AIE, students were able to develop skills in using the program to determine the effects and impact on the environment of materials, construction methods, and service life of a building. The entire course consisted of conducting LCA studies on various buildings on UBC and how UBC can contribute to less impact from their construction.

10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	N/A = not applicable	This course did not cover Ethics and Equity.
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	Various guest speakers spoke of the projects their firms are currently handling and how they project manage the various items they have. We didn't focus a lot on this topic, but only touched briefly on it.
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	This course explained that LCA is continuously developing and may have new knowledge develop each year. Professor Sianchuk and other guest speakers have said that LCA is a fairly new concept and as more and more people come to know if this tool, there will be many developments in the LCA industry.

Author Reflection – Matthew Yam (#54811104)

Discussion of your previous exposure/experience with sustainability and LCA, and a brief overview of the topics covered in the course.

In the past I have had little or no exposure to Life Cycle Assessment, LCA would only be briefly mentioned in some classes when the professor tries to incorporate a sustainability perspective. Therefore my understanding of LCA has been limited to it being a process where materials and their life spans are accounted in a “life cycle analysis”. Even in the Environmental Impact Studies course this semester, we only briefly touched on LCA and only stated it was an up and coming way of assessing the environment. The sustainability topics covered in that course was more qualitative and included a wide range of issues and techniques used to tackle them. It was not specifically targeted at analysis and determining the problems behind those issues in a quantitative way, which is what engineers do. However now nearing the end of this course I understand the concepts of LCA and the detailed components that are required for LCA studies. The topics covered in class to help with this understanding included discussions on what LCA entails (based on ISO standards) and the steps to approach it. The class introduced how LCA studies are applied in the real world, through the course project, working with the Green Building Manager at UBC. We were exposed to the three main steps of LCA, which included: Goal and Scope, Inventory Analysis, and Impact Assessment. We were involved in discussing the application of LCA studies in LEED certifications and other outputs from a LCA study. We were presented the tools that benefit LCA studies and the drawbacks from using them. We also familiarized ourselves with the various terms used in LCA.

Brief overview of what interested you about this course and the final project LCA study.

During the course and working through the final project LCA study, I found it very interesting finding out how the outcome of a LCA study can be used in building projects. I gained an understanding in how certain materials and building techniques can be beneficial or can have adverse effects for the environment; this was possible after trial and error running the model of certain buildings in the Athena EIE software and looking at what changes in the building components has on the reference flow. It made me realize how important design decisions are during the concept stages of a project, as most of the materials and key choices are made during this stage. Therefore, in order to make a building project sustainable, LCA studies would have to be involved early on in the design process in order to make an impact.

Write down any special interests or thoughts that you've had during this project.

During the project it was made apparent to me that a lot of things that claim to be environmentally friendly or sustainable may not actually be. It may just be companies trying to 'greenwash' their products as a marketing tool. For example, are electrical cars really that much more sustainable than normal cars. A LCA study and EPDs would be needed in order to find out the real impacts of producing these cars. The marketing tools used by automotive companies focus just on operation. But that is only a portion of the life cycle of that product, the material use and energy and resources spent to create them play a huge role in environmental impacts. It will be interesting to see how the industry adapts to LCA studies, as more and more people start to demand concrete evidence on the sustainability of the products they are spending money on.

Mark and briefly comment on which of the 12 CEAB graduate attributes you believe you had to demonstrate during your CIVL498C experience.

	Graduate Attribute			By: Matthew Yam (#54811104)
	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.	A = applied	For Final Project Stage 1 & 2 I had to draw in my fundamental knowledge of buildings and materials in order to apply and change the building model through the use of the Athena EIE software.

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	Final Project Stages 1, 2 and 3 required this attribute to complete the tasks given at each of the stages. I had to deduce where I needed to make changes and why in order to achieve a certain goal in the Athena Environmental Impact Estimator. In addition, the Airplane activity in class was good at providing a simple practical experience where we can understand the complex relationships in the LCA study process in the Final Project.
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.	DA = developed & applied	This included the use of the Athena EIE software and figuring out the impacts of making changes to building elements. We had to work with a range of data sets in order to test and figure out the best ways to reach our goals.

4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	I = introduced	Discussed how we would go about starting and tackling a LCA study and all the different variables we need to consider when doing so.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	IDA = introduced, developed & applied	The Athena Environment Impact Estimated was a simple yet effective tool that allowed us to achieve the goals for our LCA studies. We were able to develop a sense of the software, including the origins of the database it draws from. There was also good support from the professor and TA on how to use the program. Excel skills were further developed as a part of this, as it helped facilitate presenting and organizing the data outputted from the AthenaEIE. Other software such as, TALLY, Revit and SimaPro

				was also introduced to showcase the wide range of tools available to use for a LCA study.
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	In class activities, team assignments and final project groups allowed students to work together and share ideas to achieve a common goal. There were a lot of chances for this throughout the course.
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	DA = developed & applied	The professor would try to include everyone into discussions in class, this was good to help people get engaged in the topic and not just sit there listening to a lecture. This was effective in allowing students to develop their understanding and ideas on the spot and deliver them in a coherent manner. Class assignments and Project tasks also gave a chance for students to apply their skills in collecting research and presenting it in a well formatted and concise manner.

		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.	ID = introduced & developed	The final project in the end involved producing a report for a real life client and this allowed students to understand the importance of their work in the professional world. The students needed to pay closer attention to their quality of work as it has real life impacts and not just for grades.

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	In class we discussed the many implications of LCA studies. The information from these studies can affect everyone in the world and we were made to understand the many different implications of it. Whether it is the LCA study being conducted for legal reasons, or the client wanting to know the potential human health impacts, or just to benefit the ecosystem we all live in. The work done in a LCA study is directly linked to sustainability issues where it is used.
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	A = applied	When working on our final projects. We had to realize that what we were working on wasn't just for grades and were eventually for a real client. This meant that we had to be accountable for our work and must demonstrate ethical values and equity, in order to do our part in the research and deliver something useable

				to the client.
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.	ID = introduced & developed	Guest lectures and the professor delivered a good understanding on how things worked in the professional world. They explained the challenges and benefits of working in their field and highlighted some risks or changes that needed to be made in order to be successful.
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.	I = introduced	The professor explained how the use of LCA studies is growing in the world and how it can one day be a big part of all projects. The significance of such studies appeal to me as the world is currently trending towards sustainable development. The course allowed my understanding in environmental studies to be beyond just buzz-words and sayings, it opened the opportunity for me to understand the facts and figures that actually make something more environmentally friendly and the process in doing so. It makes me think twice about things that claim to be environmentally friendly.

Appendix B: Figures

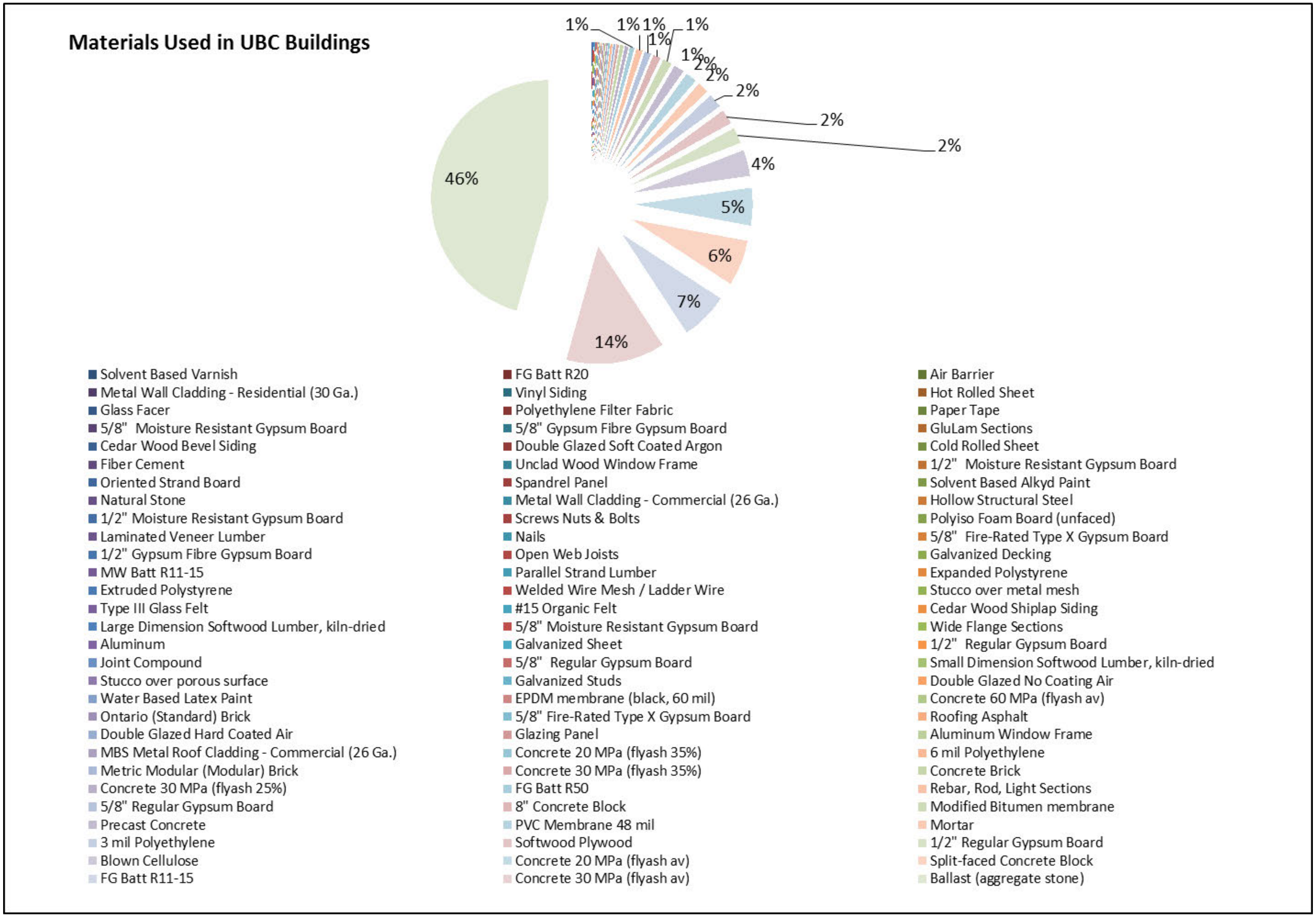

Figure 1: Materials used in UBC Buildings

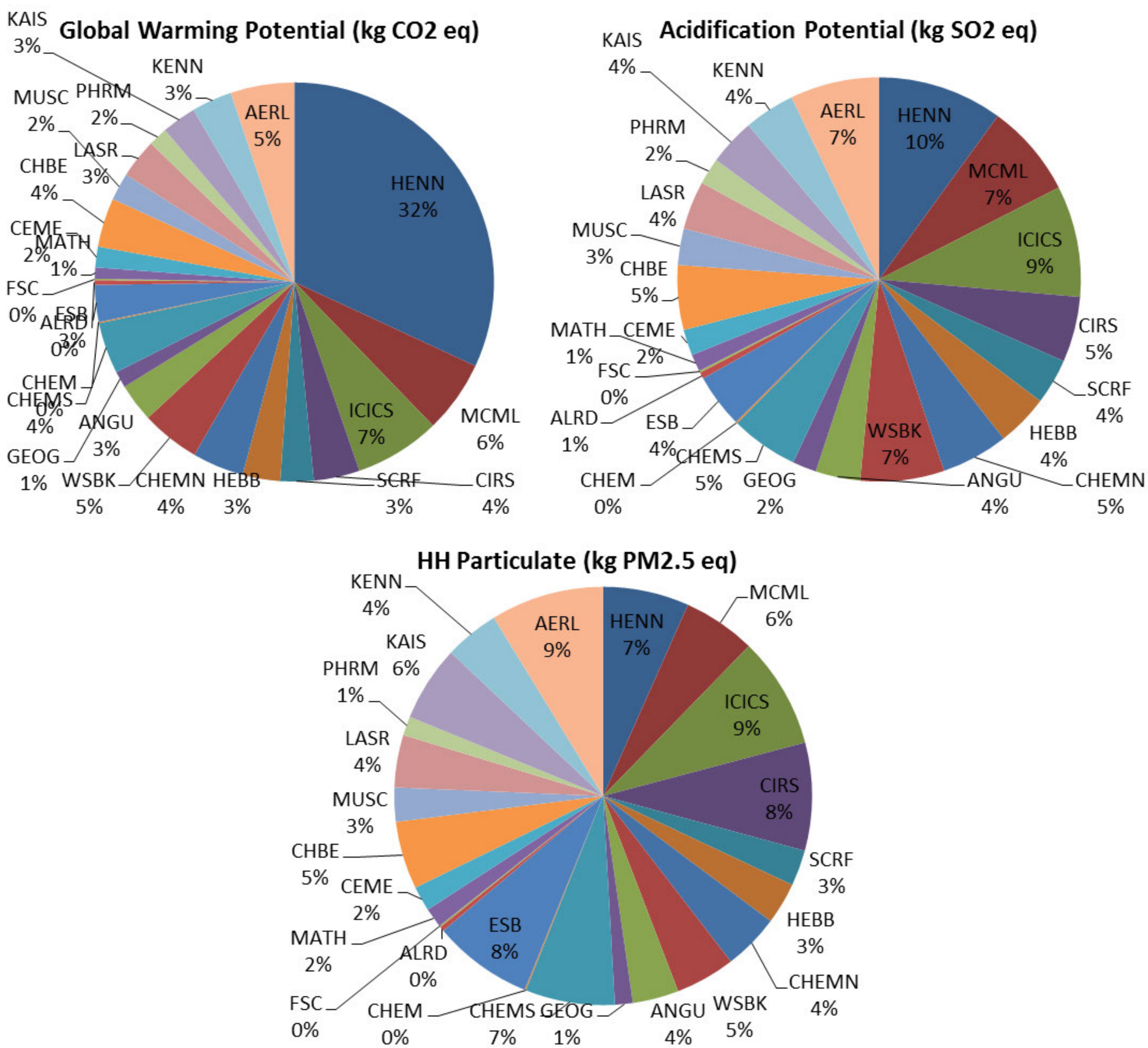

Figure 2: Global Warming Potential, Acidification Potential, and HH Particulate

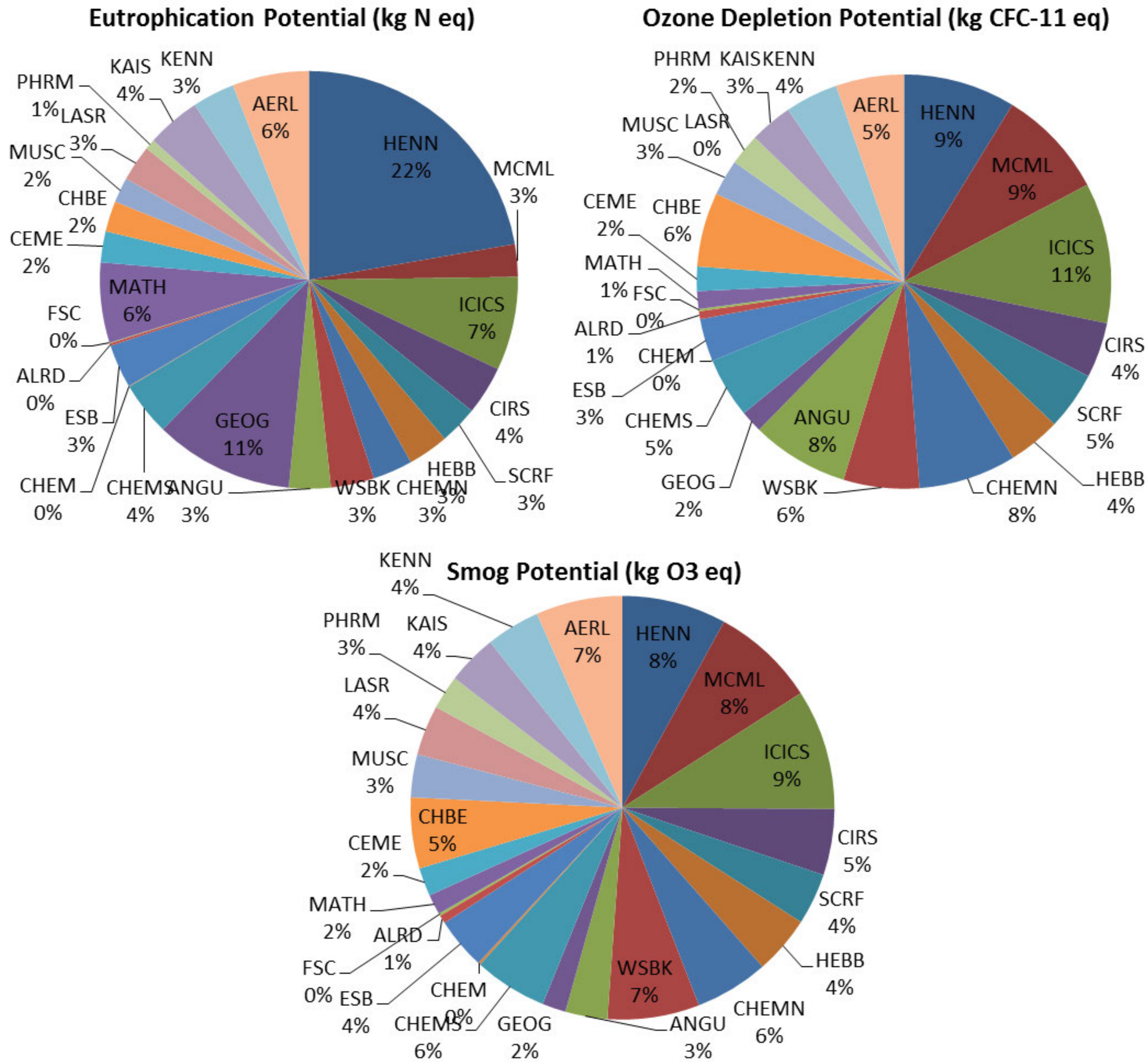

Figure 3: Eutrophication Potential, Ozone Depletion Potential, and Smog Potential

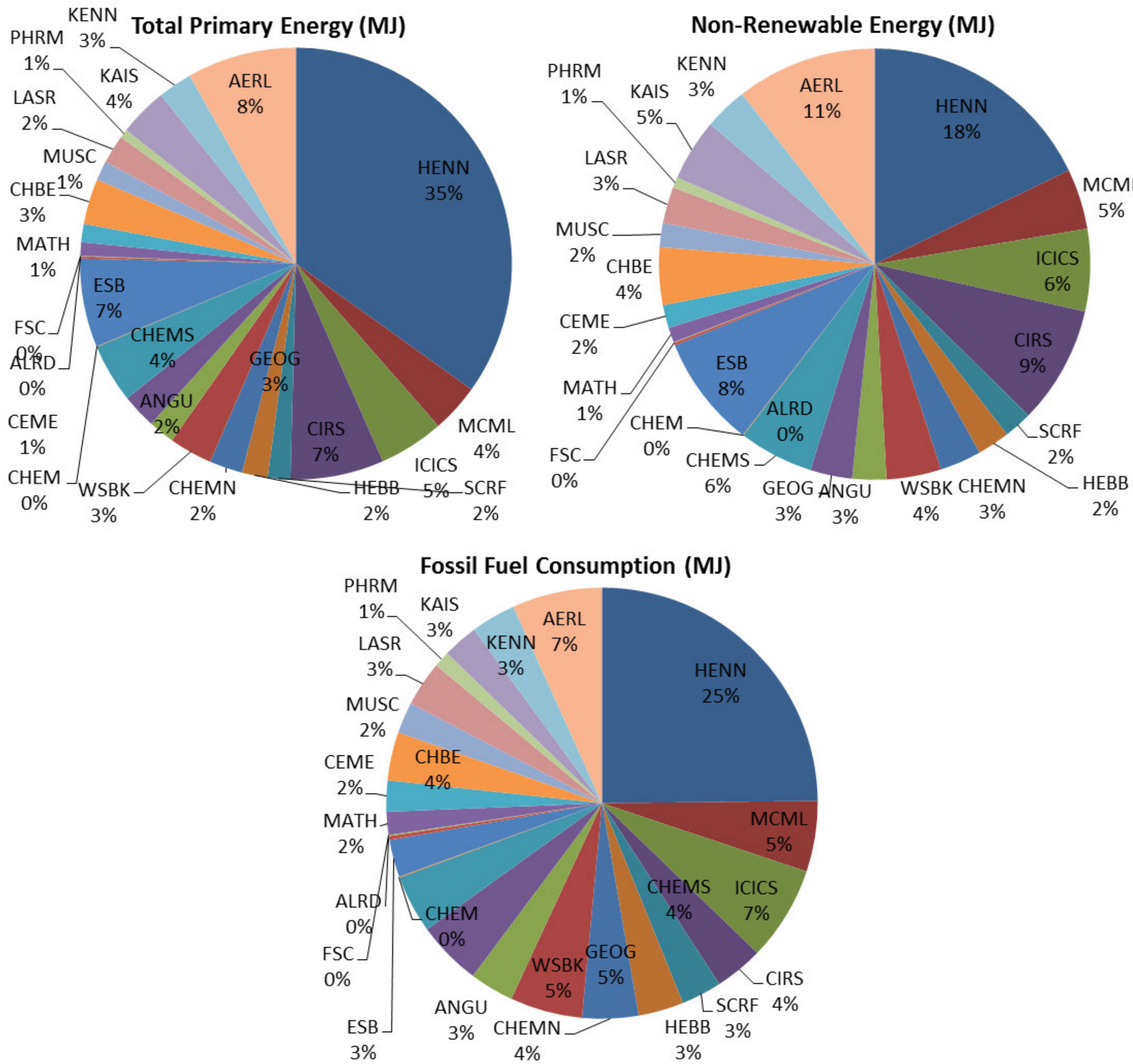

Figure 4: Total Primary Energy, Non-Renewable Energy, and Fossil Fuel Consumption

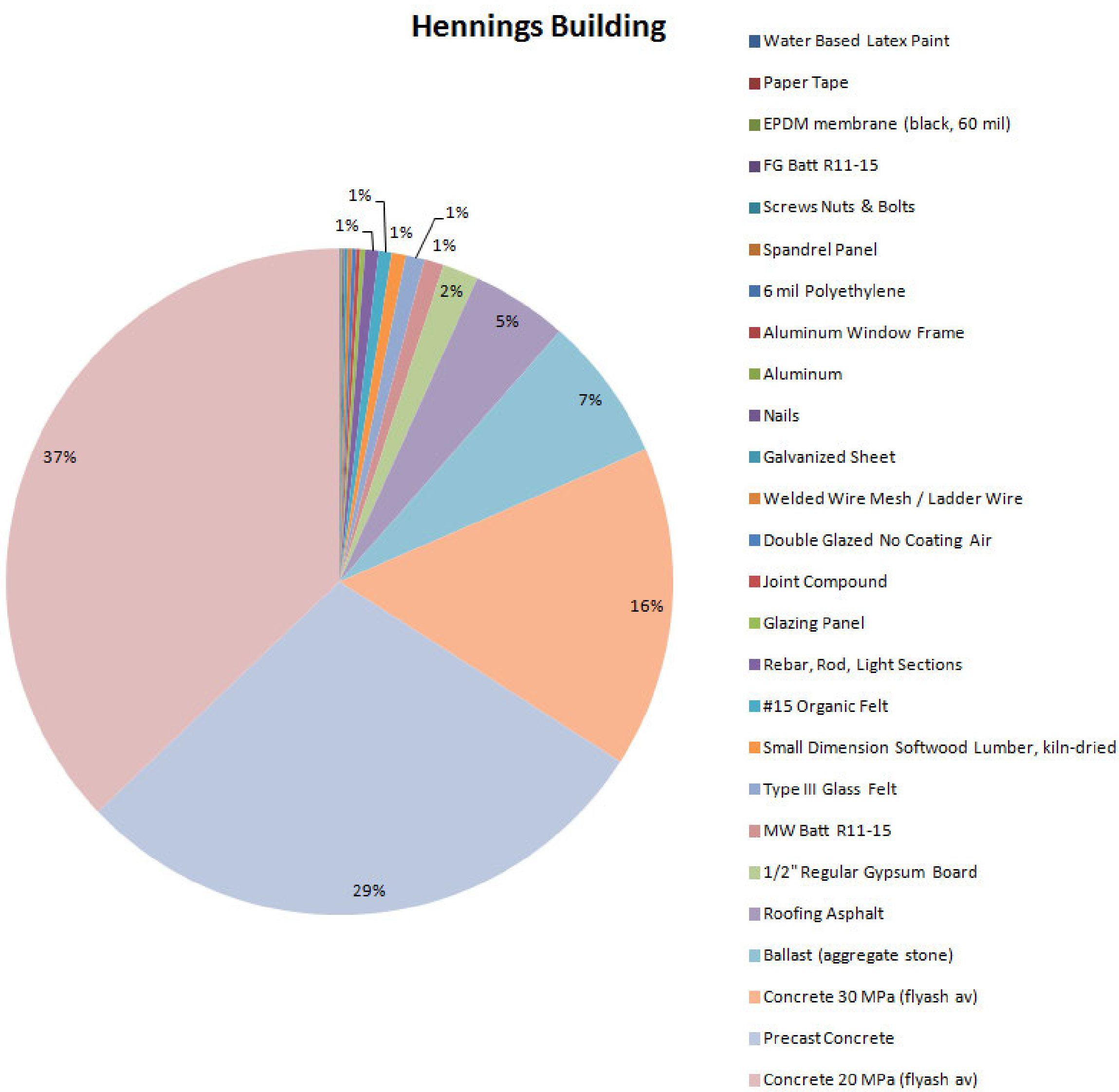

Figure 5: Hennings Building Material Composition

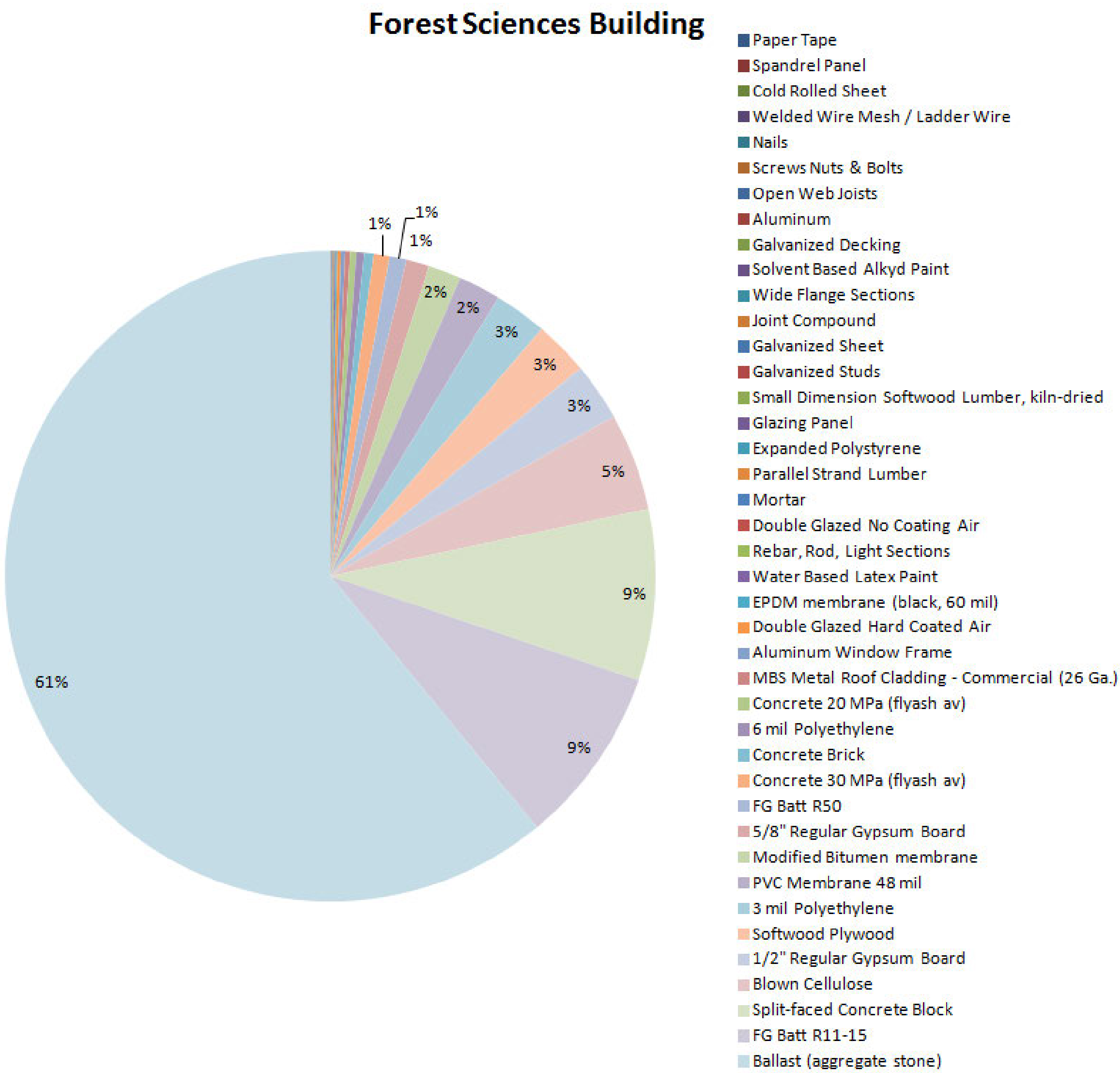

Figure 6: Forest Sciences Building Material Composition

Option 4. whole-building life-cycle assessment (3 points)

For new construction (buildings or portions of buildings), conduct a life-cycle assessment of the project's structure and enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building, in at least three of the six impact categories listed below, one of which must be global warming potential. No impact category assessed as part of the life-cycle assessment may increase by more than 5% compared with the baseline building.

The baseline and proposed buildings must be of comparable size, function, orientation, and operating energy performance as defined in EA Prerequisite Minimum Energy Performance. The service life of the baseline and proposed buildings must be the same and at least 60 years to fully account for maintenance and replacement. Use the same life-cycle assessment software tools and data sets to evaluate both the baseline building and the proposed building, and report all listed impact categories. Data sets must be compliant with ISO 14044.

Select at least three of the following impact categories for reduction:

global warming potential (greenhouse gases), in CO2e;

depletion of the stratospheric ozone layer, in kg CFC-11;
acidification of land and water sources, in moles H+ or kg SO2;
eutrophication, in kg nitrogen or kg phosphate;
formation of tropospheric ozone, in kg NOx, kg O3, or kg ethene; and
depletion of nonrenewable energy resources, in MJ.

Figure 7: LEED Building life-cycle impact reduction reference section.

(U.S. Green Building Council, 2013)

Appendix C: References

Bare, J.C. Hofstetter, P. Pennington, D.W. and Udo de Haes, H.A. (2000). Midpoint versus Endpoints: The Sacrifices and Benefits. *Int. J. LCA, 5(6), 319-326. Retrieved November, 2014 from: http://www.clu-in.org/conf/tio/lcia_092309/ijlca-midpt-endpt.pdf*

Gagilano, N. (2013). Critical Review of Fred Kaiser Building. *CIVL 498C, Final Project Report.*

Jensen, A.A. Hoffman, L. Møller, B.T. Schmidt, A. (1997). Life Cycle Assessment (LCA): A guide to approaches, experiences and information sources. *European Environment Agency: Environmental Issues Series, 6(-), 11.*

Osphelt, Christoph. The Metrics of Sustainable Buildings. *Retrieved November, 2014 from: http://www.technicalguidelines.ubc.ca/files/sustainable_bldgs.pdf*

Qiu, Z. (2013). Life Cycle Assessment – Henry Angus Building. *CIVL 498C, Final Project Report.*

Trusty, W. (2001) Introducing an Assessment Tool Classification System. *The Athena Sustainable Material Institute. Retrieved November, 2014 from: http://aesl.hyu.ac.kr/resource/blcc/assess-typology-tool.pdf*

Trusty, W. and Horse, S. (2005). Life Cycle Tools Around the World. *Building Design and Construction – Life Cycle Assessment and Sustainability. 3(-), 12.*

U.S. Green Building Council. (2013). LEED Reference Guide for Building Design and Construction. *Retrieved November, 2014 from: http://www.usgbc.org/leed/v4/*

U.S. Green Building Council. (2014). LEED BD+C: New Construction, v4. *Retrieved November, 2014 from: http://www.usgbc.org/credits/new-construction/v4*

United States Environmental Protection Agency. (2014). Overview of Greenhouse Gases. *Retrieved November, 2014 from:* *http://www.epa.gov/climatechange/ghgemissions/gases.html*

University of British Columbia. (2010, June). Vancouver Campus Plan, Part 3: Design Guidelines. *Retrieved November, 2014 from:* *http://planning.ubc.ca/sites/planning.ubc.ca/files/documents/planning-services/policies-plans/VCP_Part3.pdf*

University of British Columbia. (2014). UBC Sustainability: LEED @ UBC. *Retrieved November 2014 from: http://sustain.ubc.ca/campus-initiatives/buildings/leed-ubc*

University of British Columbia. (2014). UBC Technical Guidelines: Sustainability. *Retrieved November, 2014 from:* *http://www.technicalguidelines.ubc.ca/technical/sustainability.html*

University of British Columbia. (2014). UBC Technical Guidelines: Life Cycle Costing Toolkit. *Retrieved November, 2014 from:* *http://www.technicalguidelines.ubc.ca/technical/life_cycle.html*

University of British Columbia. (2014). UBC Technical Guidelines: Performance Objectives. *Retrieved November, 2014 from:* *http://www.technicalguidelines.ubc.ca/technical/performance_obj.html*

University of British Columbia. (2014). UBC Vancouver Campus Climate Action Plan. *Retrieved November, 2014 from:* *http://sustain.ubc.ca/sites/sustain.ubc.ca/files/uploads/CampusSustainability/CS_PDFs/PlansReports/Plans/UBCClimateActionPlan.pdf*

Wang, W. (2013). Life Cycle Assessment – Center for Interactive Research on Sustainability (the Wesbrook Building). *CIVL 498C, Final Project Report.*

Appendix D: Sample Life Cycle Costing Analysis (Buchanan)

Appendix E: UBC RFI Evaluation Criteria