the ATHENA™
Sustainable Materials Institute

Combined Research Report
Comparative Life Cycle Environmental Assessments:

Red River College, Princess Street Campus Project

Prepared for:

The Province of Manitoba, Manitoba Hydro, & Corbett Cibinel Architects

Mayo Replacement School
Jackson Triggs Winery

Prepared for:

Green Building Services Group
Royal Canadian Mounted Police

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1 Introduction

This document has been prepared from two separate reports recently completed by the Athena Sustainable Materials Institute (the Institute) in conjunction with the Canadian Green Building Challenge 2002 (GBC '02) process. The report presents the results of comparative life cycle assessments of each of three separate buildings with corresponding benchmark designs using the *ATHENA™ 2.0* software, the Environmental Impact Estimator.

One of the two reports was prepared for The Province of Manitoba and Manitoba Hydro, through Corbett Cibinel Architects (CCA)which retained the Institute to complete a comparative life cycle environmental impact assessment of the Red River College, Princess Street Campus development with that of a typical practice green field development of the site.

The other report was commissioned by the Green Buildings Services Group of the Royal Canadian Mounted Police (RCMP). There were two main objectives:

1. to describe the life cycle assessment (LCA) concept and the importance of using an LCA decision-making framework when choosing between various design elements for typical detachment buildings across the country; and
2. to demonstrate the application of life cycle assessment for two projects, the Mayo Replacement School and the Jackson Triggs Winery, which were also being assessed under the GBC '02 environmental assessment framework.

The reports have been combined here to provide a more concise document for inclusion in the GBC '02 CD being prepared to facilitate knowledge transfer within the building community as a whole.

Section 2 of this combined report provides background on the life cycle assessment methodology in general, and it value to the building community.

Section 3 describes the *ATHENA™ 2.0* software and the specific measures used to combine and compare final building designs to the relevant benchmarks.

Sections 4 and 5 present the detailed approach and results for the case study buildings, essentially as presented in the original reports.

2 Life Cycle Assessment

2.1 What is Life Cycle Assessment?

Life cycle assessment (LCA) is a process whereby the environmental burdens associated with a product, process or activity are evaluated by quantifying energy use, other resource and material use and environmental releases throughout the life-cycle.

Life cycle assessment was first developed in the 1970’s and has been undergoing continuous improvement and adoption by standards organizations around the world. The ISO 14040 standard from the International Organization for Standardization has set out agreed principles for LCA studies in the following four standards publications in the Environmental Management: Life Cycle Assessment series:

- ISO 14040 — Principles and Framework
- ISO 14041 — Goal and Scope Definition and Inventory Analysis
- ISO 14042 — Life Cycle Impact Assessment
- ISO 14043 — Life Cycle Interpretation

The 14040 and 14041 standards set out the methods for analyzing the physical transformation of resources and energy into products or services. The 14042 standard deals with the problems of distilling and understanding the potential implications of the large set of environmental inputs and outputs typically developed during the inventory phase of a study, as described below. The 14043 standard extends the LCA beyond quantitative measurements and relationships to a point where an evaluation or judgment is made, which may be a simple statement of what is better or worse.

As per the above standards, life cycle assessment typically involves three phases. It starts with an initiation phase where the purpose, scope, system boundaries and data categories for the study are specified. The initiation phase is critical. It is here that the scope of the study is determined by answering such questions as, what are we trying to achieve with this LCA, who will use the results, and how. The definition and level of detail specified for the system boundary of the product system will greatly affect the usability of the information. The initiation phase also defines the study’s common assumptions related to the level of detail, the emission profiles for common fuels, and conversion factors to name but a few. The data categories selected in the initiation phase and their source can have a dramatic effect on the usefulness and cost of the LCA, and how they are measured or calculated will influence the mass balance of the study.

The inventory phase is the heart of any LCA — an assessment is not possible without completing an inventory analysis, and the quality of inventory stage results determines the quality of all subsequent analysis results and, ultimately, of the decisions based on the assessment. Inventory analysis is the physical accounting or tracking of energy and material usage and environmental emissions to air, water and land. Essentially, inventory analysis is a representative balance sheet where resource inputs and waste outputs are tracked for a product over its defined life cycle. The three most important aspects surrounding a life cycle inventory analysis include:

- the system boundary for the inventory;
- the allocation method used; and
- the functional unit.

Co-product allocation, which deals with how we partition environmental inputs and outputs across a multi-product system, is often a contentious issue for LCA practitioners. Allocation may be done on the basis of the relative mass or volume of outputs, the relative energy use or the relative value of the co-products. Whichever method is used the results can be quite different and it is important that the users of the study understand the methods used and their implications.

The functional unit for the study is an important consideration because all inputs and outputs will be developed in relation to the defined functional unit, be it a cubic meter of concrete, a concrete wall, or a complete concrete building.

Impact assessment is still at an early stage in its development and is often contentious because it involves assessing the ultimate consequences of the inventory burdens. To date most LCA studies have concentrated on the inventory phase, with impact assessment confined to grouping and characterizing the inventory results in terms of potentials for impacts in various categories such as global warming, ozone depletion and acidification. Researchers may also normalize the inventory results against a more relevant measure- such as annual per capita releases of CO2.

2.2 Why is Life Cycle Assessment Useful?

For now and into the foreseeable future, sustainable development is about making better decisions with respect to environmental, economic, and social concerns. Life cycle assessment is the most widely used method to help support these types of decisions from the environmental perspective. It can be applied at the level of individual consumer products or processes with short lives, or at the level of complex, long-lived products such as buildings.

Businesses are using LCA to help guide cost reductions in operations and to increase sales through supporting and better understanding the needs of an ever increasing, environmentally aware market place. Innovative companies are using LCA to measure, benchmark and communicate aspects of their impact on sustainability. LCA-oriented systems provide accurate and timely information on the energy, material and environmental efficiency of a company, which in turn can support strategic planning.

Governments have many of the same concerns as businesses and are increasing their efforts to green their respective operations by way of “green procurement practices”. Governments are also want to demonstrate leadership in the adoption of sustainable practices and environmental stewardship. Again LCA is a valuable tool because it not only offers an objective and consistent product comparison framework, but it ensures that purchases today are not evaluated on an initial impact basis, but rather over the full life cycle of competing products and services.

If we look at buildings, which are the subject of primary interest here, LCA offers an objective, quantitative basis for assessing the environmental benefits of alternative design or material selection choices. It is therefore an essential element in the design toolkit, along with the various green building rating and certification systems that have been developed to foster more sustainable building design, construction and operations. Those systems do an admirable job of promoting and making possible a better integration of environmental concerns with cost and other traditional decision criteria, and of fostering and facilitating integrated design practices and a holistic approach. But while these systems generally capture the complicated, web-like relationship between a building's construction and operations and its impacts on human health and the environment, there tends to be a disconnect between broad understanding of this relationship and the specifics intended to foster appropriate decisions. In a sense, there is an absence of a clear objective function, or at least a failure to always have the objective function in the forefront.

The ultimate objective from an environmental perspective is to minimize the flows from and to nature: the use of natural resources of all kinds and emissions to air, land and water throughout a building's complete life cycle. Until we know much more at a hard scientific level, it is difficult to conceive any more sensible route to environmental sustainability. The failure to maintain a clear objective function in building assessment systems is most notable in the case of material selection criteria and, to a lesser extent, in the energy use criteria. In fact, defining "sustainable materials" and encouraging their use seems to be one of the biggest challenges for the developers of green building rating systems. That challenge can best be met by the use of LCA and LCA-based decision support tools, and ultimately by their integration in whole building rating and certification systems.

The problem is most easily understood in the context of the credits or scores assigned in rating systems for building material choices. It arises because material credits have typically evolved from a consensus-based understanding of environmental issues, understandings that, in some cases, have taken on an aura of conventional environmental wisdom that does not always stand up to objective analysis. As well, there is a risk of confusing means and ends, with the means becoming objectives in their own right to the possible detriment of environmental performance.

A couple of examples make the problem clear. Rating systems typically offer substantial credit for the use of recycled materials, the presumption being that recycled materials will automatically result in reduced environmental burdens. However, this may not always be the case, and recycling in any given situation may be good or bad. For example, recycling can save landfill space, but the process of recycling a given product may take more energy and adversely affect air quality more profoundly than would production from virgin resources. The focus on recycling ignores this possibility and implicitly gives more weight to solid waste and resource depletion issues than to global warming or other measures.

The point is not that one issue or indicator is more important than the other, but that commonly held beliefs or assumptions appear to take precedence over data and facts in the decision process. In fact, recycling is probably the best example of a confusion of ends with means. Recycling has always been only a means to the objective of reduced flows from and to nature, but over time it has taken on the mantle of an objective in its own right.

A somewhat subtler example is credits for the use of rapidly renewable materials. These kinds of credits are intended to reduce the use and depletion of finite raw, and long cycle renewable materials by replacing them with rapidly renewable materials. Among a number of problems with a credit like this, is the fact that it ignores the value of land as a finite resource as well as the implications of all of the fertilizers, pesticides, insecticides, etc., that may be used in the process of producing rapidly renewable materials. Nor is there any a priori scientific reason for preferring a short cycle renewable to a long cycle renewable, let alone for picking the length of rotation cycle that should be preferred.

Similar kinds of problems arise with even the most sacred of rating system credits, those for operating energy use. Not all energy is equal: combustion emissions differ by energy form, and the upstream, pre-combustion implications of producing and moving different energy forms can be even more significant. As a result, a credit system that promotes minimal energy use without regard for the form of that energy may be misleading, especially if it results in the use of materials or construction techniques that have significant resource use or emission implications in their own right.

An argument often advanced to support giving precedence to the minimization of operating energy irrespective of material use implications is that operating energy use dominates the total of operating plus embodied energy. While this is generally true, the argument ignores other potentially serious environmental implications of too narrow a focus on operating energy. For example, toxic releases to water are more likely to result from the production of building materials than from building operations, and we must therefore cast our net wide enough to catch a full range of potential effects.

The key point is that we should strive to encompass the full range of environmental effects over the full life cycle and get beyond proxy measures like recycled content, or narrowly focused preferences like the preference for short- versus long-rotation renewables. LCA is currently the only method for doing that, and even if LCA does not cover all of the issues of concern in a building assessment, it establishes a much better basis for informed environmental choices and therefore for assessing the relative merits of a building from a materials use perspective.

It is also important to note that LCA assessments at a whole building level can take account of the relationships inherent in a building system, where the choice of one material for an application may dictate the use of other materials for thermal or other reasons. LCA will also take account of recycled content in accordance with the ISO standards for various recycling situations, but with full regard for the effects of the recycling process itself, including any related transportation.

3 *ATHENA™ 2.0*: Environmental Impact Estimator

3.1 Overview

Since the early 90s the Athena Institute has been developing an environmental life cycle assessment decision support tool known as the Environmental Impact Estimator. The ultimate objective is to assist the building community in making more informed decisions regarding the selection of design and material options that will minimize a building's life cycle environmental impact.

Currently, the software encompasses steel, wood and concrete structural products and assemblies, as well as a full range of envelope materials (e.g., cladding, insulation, glazing. etc.). It covers a building's life cycle stages from the "cradle" (natural resource extraction) through to its "end-of-life" (grave). Specifically the model encompasses the following building life cycle stages:

- *Product manufacturing*, which includes resource extraction, resource transportation and manufacturing of specific materials, products or building components;
- *On-site construction*, which includes product/component transportation from the point of manufacture to the building site and on-site construction activities;
- *Maintenance and replacement*, which includes life cycle maintenance and replacement activities associated with the structure and envelope components based on building type, location and a user defined life for the building; and
- *Building "end-of-life"*, which simulates demolition energy and final disposition of the materials incorporated in a building at the end of its life.

The software also includes a calculator to convert operating energy to primary energy and related emissions to allow users to compare embodied and operating energy environmental effects over the building's life. The operating energy calculator requires a separate estimate of operating energy as an input to the model.

In terms of results, the software provides a detailed environmental life cycle inventory of the embodied effects associated with the building as well as a set of six summary measures. These summary measures include primary (embodied) energy and raw material use; greenhouse gas potential (both fuel and process related); measures of air and water pollution; and solid wastes.

Results are provided in terms of building totals by assembly as well as on a square meter of gross floor area basis. The latter measure is useful for comparing buildings of similar function but different size. The unit area is also useful for developing benchmarks to compare future designs and material selections.

For use in Canada, the model is divided into six geographic regions represented by Vancouver, Calgary, Winnipeg, Toronto, Montreal and Halifax. When any of these regions are selected, the software relies exclusively on Canadian data, representing average or typical manufacturing technologies and appropriate modes and distances for transportation. Other cities listed in the software designate US regions and their selection turns on the relevant energy, transportation and product life cycle inventory databases.

3.2 Embodied Energy, Global Warming Potential and Other Impact Measures

Embodied energy includes all energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in feedstock materials that are also used as common energy sources (for example, natural gas used as a raw material in the production of various plastic resins). In addition, the model also captures the indirect or pre-combustion energy use associated with processing, transporting, converting and delivering fuel and energy.

Solid waste is reported on a mass basis in kilograms and is generally self-explanatory. No attempt has been made to further categorize emissions to land as either hazardous or non-hazardous. Few, if any, of the materials specified in a typical building project emit meaningful quantities of hazardous solid waste.

All other measures are indices requiring more explanation and interpretation. They have been developed because of the difficulty of using and interpreting detailed life cycle inventory results. For example, it takes considerable expertise to understand and appreciate the significance of the individual emissions to air and water. Both categories encompass a relatively large number of individual substances with varying environmental impacts. In the case of raw resource use, there is no real basis for comparison from one material to another in terms of environmental impact. The model therefore compiles related numeric results into indices that summarise the results by indicating potentials for environmental impacts.

Raw resource use can be measured in common units such as tonnes, but a unit of one resource like iron ore is not at all comparable to a unit of another resource like timber or coal when it comes to the environmental implications of extraction. Since the varied effects of resource extraction, (e.g., effects on bio-diversity, ground water quality and wildlife habitat, etc.) are a primary concern, we want to make sure they are taken into account. The problem is that while these ecological carrying capacity effects are as important as the basic life cycle inventory data, they are much harder to incorporate for a number of reasons, especially their highly site-specific nature.

Our approach was to survey a number of resource extraction and environmental specialists across Canada to develop subjective scores of the relative effects of different resource extraction activities. The scores reflect the expert panel ranking of the effects of extraction activities relative to each other for each of several impact dimensions. The scores were combined into a set of resource-specific index numbers, which are applied in the software as weights to the amounts of raw resources used to manufacture each building product.

The values shown for the *Weighted Resource Use* measure are the sums of the weighted resource requirements for all products used in each of the designs. They can be thought of as "ecologically weighted kilograms", where the weights reflect expert opinion about the relative ecological carrying capacity effects of extraction. Excluded from this measure are energy feedstocks used as raw materials. Except for coal, no scoring survey has been conducted on the effects of extracting fossil fuels, and hence, they have been assigned a score of one to only account for their mass.

Global warming potential is estimated using carbon dioxide as the common reference standard. All other greenhouse gases are referred to as having a "CO_2 equivalence effect" which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the gas over time.

As yet no consensus has been reached on the issue of the most appropriate time horizon for global warming calculations. However, international policy conventions typically use the 100-year time horizon basis for the equivalence measure and we have adopted this convention for reporting purposes. The 100-year global warming potential (GWP) reflects equivalent CO_2 kg and is calculated as follows:

$$\text{GWP100 (kg)} = CO_2\text{kg} + (N_2O\text{g} \times 296 + CH_4\text{g} \times 23) / 1000$$

While greenhouse gas emissions are largely a function of energy combustion some products also emit greenhouse gases during the processing of raw materials. Process emissions often go unaccounted for due to the complexity associated with modeling manufacturing process stages. One example where process CO_2 emissions are significant is in the production of cement (calcination of limestone) prior to its use in concrete manufacture. Because *ATHENA™ 2.0* uses a detailed life cycle modeling approach all relevant process emissions of greenhouse gases are included in the resultant index.

Air and water pollution measures are similarly intended to capture the pollution or human health effects of groups of substances emitted at various life cycle stages. In this case we used the commonly recognised and accepted critical volume method to estimate the volume of ambient air or water that would be required to dilute contaminants to acceptable levels, where acceptability is defined by the most stringent standards (i.e., drinking water standards).

ATHENA™ 2.0 calculates and reports these critical volume measures based on the worst offender -- that is, the substance requiring the largest volume of air and water to achieve dilution to acceptable levels. The hypothesis is that the same volume of air or water can contain a number of pollutants. However, there are concerns about the cumulative or synergistic effects of some substances and we therefore expect to further refine our approach in the future.

The following additional potential impact measures of interest to the GBTool rating system being used in the Green Building Challenge are not typically reported by Athena. These measures were therefore derived from the software’s detailed inventory results for both embodied effects and annual operating energy.

Acidification effects are estimated using sulphur dioxide as the common reference standard, with all other acid gas releases referred to as having a "SO_2 equivalence effect, which is simply a multiple of the acidification potential (acid rain capability) of sulphur dioxide.

$$\text{Acid Potential kg} = SO_2\,\text{kg} + (0.07 \times NO_2\,\text{kg} + 1.07 \times NO\,\text{kg} + 1.88 \times NH_3\,\text{kg} + 1.6 \times HF\,\text{kg} + 0.88 \times HCL\,\text{kg})$$

Eutrophication provides a measure of the impairment of surface waters caused by excessive (non-natural) inputs of primarily phosphorus and nitrogen compounds: in other words, an over-fertilization of surface waters by nutrients that were previously scarce. This can lead to the proliferation of algae. Phosphates are one common reference standard for eutrophication effects. All other eutrophication contributing emissions to air and water are reported as a weighted multiple of their equivalence effect relative to phosphates, calculated as follows:

Eu. Potential kg= PO_3kg+NO_xkg*.13+N_2Okg*.27+CODkg*.022+BODkg*.05+ NH_4kg*1.1+PO_4kg*3.06

Photochemical Ozone Potential (PCOP) provides a measure of low-level atmospheric smog. Numerous sources exist for calculating PCOP, but we limited the calculation to those broad substance groups having an equivalence effect of ethane as documented in GBTool. The calculation is as follows:

PCOP in kg = CH4 kg x 0.007 + Non-methane hydrocarbons (NMHC) kg x 0.33

4 Red River College, Princess Street Campus

4.1 *Introduction*

The Red River College, Princess Street Campus Project incorporates three buildings adjoined by a suspended atrium in downtown Winnipeg. The project also incorporates the reuse of an existing building, existing building facades and a considerable number of materials reclaimed from the previous site development in various applications throughout the new development. In contrast, the comparative benchmark development was assumed to be a completely new, single building on the site. While providing a similar functional space it was of a more basic, generic design than that achieved with the actual site development.

In this case, we undertook to assess the life cycle impact of the structure and envelope of these two diametrically opposed developments assuming a 75-year life expectancy for both projects.

4.2 *Basic Approach*

Both building designs were modelled using the software’s Winnipeg regional location indicator. Results are provided here as a set of six environmental indicators, in terms of building totals as well as on a square meter of gross floor area basis. The environmental indicators include primary energy and raw material use, air and water pollution, global warming potential and solid waste production.

The actual development incorporates considerable reuse elements which reduces its overall embodied effects. The reuse elements included in our analysis include:

- reuse of the existing 6-storey wood and clay brick structure on William Avenue;
- reuse of the existing heritage facades on the Princess Street block;
- reuse of reclaimed tyndall stone on both the Adelaide and Princess blocks and the four story addition to the 6 story existing building, and
- reuse of reclaimed clay brick for the shear walls of the Princess block building.

We accounted for these reuse elements in the following ways:

- The reuse of the William street building resulted in our not modelling the building, but including its gross floor area contribution to the project, thereby reducing the overall environmental burden of the actual project development.
- The reuse of the heritage facades on the Princess block was also excluded from the model, which again had the effect of these clay brick facades entering the model free of any burdens.
- The reuse of reclaimed clay brick and tyndall stone was handled differently. For the tyndall stone reuse, we negated the embodied effects of producing and transporting the stone to Winnipeg, but included the additional mortar and construction effects of putting the stone in place. Modelling the clay brick shear walls involved a similar material production and transport credit and the addition of the same on-site

construction effects as for the tyndall stone, but we also included a credit for the shear wall material it was displacing.

Other minor reuse elements were discussed with CCA, but no additional quantitative information was provided beyond the reuse considerations noted above.

ATHENA™ 2.0 also has the capability to accept and integrate the operating energy estimates developed for the two designs as part of the GBC project. The Impact Estimator’s operating energy conversion calculator picks up where most simulation tools leave off: *ATHENA™ 2.0* takes the reported operating energy use by fuel type and converts it to primary energy use inclusive of upstream or pre-combustion effects and reports related emissions to air, water and land. One note of caution is appropriate here; the benchmark operating energy estimates were developed based on the three buildings not on the single building design that was modelled. Hence, the values for the benchmark are probably overstated somewhat, but to what degree is beyond the scope of this study.

For both the benchmark and the final design, interior fit-up beyond partition walls was also excluded from the study. Hence the reported results provide a more conservative estimate (i.e., lower) of the total life cycle environmental impacts of constructing and maintaining both the benchmark and actual building designs over their respective expected lives. If all interior finishes, furniture and landscaping had been factored in over the useful life of the two designs, the full environmental impacts would certainly be greater than reported in this study.

4.3 Design Documents and Bill of Materials Data

The Institute retained the services of Morrison Hershfield’s Buildings Group to review the set of “as built” drawings for the actual project design as provided by CCA. The benchmark design structure and envelope were then developed in consultation with CCA staff taking into consideration typical practice in Winnipeg, the site constraints and the required functional space. Morrison Hershfield prepared material quantity take-offs for both the design and benchmark developments. Morrison Hershfield also assisted with entering assembly and material data into *ATHENA™ 2.0.*

The following list outlines the major structural and envelope elements incorporated in the reference benchmark and actual design buildings.

Benchmark Building:

- 5,016 sq. m / floor x 4 floors = 20,066 sq. m (total)
- 10 bays x 6 bays = 60 bays at 9.1m x 9.1m – typical floor height = 4.6m.
- Primary Structure - WF beams with HSS columns with OWSJ floors (with concrete topping) and roof
- Foundation – column footings, perimeter footings and concrete slab-on-grade
- Interior partitions – steel studs with 5/8” type ‘X’ gypsum both sides, assumed 457 linear meters per floor with 20% openings
- Exterior walls – Stucco over metal mesh, 75mm extruded polystyrene insulation, 3 mil vapour barrier, _” moisture resistant gypsum, heavy gauge steed studs, 5/8” type ‘X’ gypsum

- Exterior wall openings – assumed 40% area is windows, with 32 windows per floor = 534 sq. m per floor.
- Roof – conventional modified bitumen membrane system with 100mm polyisocyanurate foam insulation, as per Red River College
- Assumed 30 MPa concrete with average flyash, floor and roof loads based on standard Building Code specified uniformly distributed live loads on an area of floor or roof.

Adelaide Block (includes loading dock – 225 m^2)

- 872 m2 per floor x 4 floors = 3,488 m2 (total)
- 3 bays x 3 bays = 9 bays at 8.68 m x 10 m (approx) – floor height = 4 m (approx)
- Primary Structure - WF beams with HSS & WF columns with hollow core concrete slab floors (with concrete topping) and OWSJ roof
- Foundation – no drawings provided, cast-in-place foundation walls included
- Interior partitions – from architectural drawings, steel studs with type 'X' gypsum
- Exterior walls – exterior cladding*, 75mm extruded polystyrene insulation, 3 mil vapour barrier, _" moisture resistant gypsum, heavy gauge steed studs, 5/8" type 'X' gypsum * cladding added as extra basic material - included brick, and metal siding substituting for copper shingles (copper is believed to have lower environmental burdens than metal siding, but copper is not in the *ATHENA™ 2.0* LCI database)
- Roof – conventional modified bitumen membrane system with 100mm polyisocyanurate foam insulation (HCFC and CFC free)
- Assumed 30 MPa concrete with average flyash, floor and roof loads as indicated on structural drawings

321 William Block (New)

- 354 m2 per floor x 4 floors = 1,416 m2 (total)
- 4 bays at 6.81 m x 8.95 m and 3 bays at 3.5 m x 8.95 m – floor height = 5 to 3.5 m (varies)
- Primary Structure = WF beams and WF columns with hollow core concrete slab floors (with concrete topping) and OWSJ roof
- Foundation – system of beams sitting on caissons, caissons not included
- Interior partitions – from architectural drawings, steel studs with type 'X' gypsum
- Exterior walls – Brick cladding, 75mm extruded polystyrene insulation, 3 mil vapour barrier, _" moisture resistant gypsum, heavy gauge steed studs, 5/8" type 'X' gypsum
- Roof – conventional modified bitumen membrane system with 100mm polyisocyanurate foam insulation (HCFC and CFC free)
- Assumed 30 MPa concrete with average flyash, floor and roof loads as indicated on structural drawings

315 William Block (Existing)

- 704 m2 per floor x 6 floors plus basement = 4,928 m2 (total)
- Not modeled, but 4928 m2 included in total functional space

Princess Block

- Average 2,040 m2 per floor x 4 floors = 8,167 m2 (total)
- Typical floor height = 4 m
- Primary Structure - WF beams and WF columns with hollow core concrete slab floors (with concrete topping) and OWSJ roof
- Foundation – system of beams sitting on caissons, caissons not included
- Interior partitions – from architectural drawings, steel studs with type 'X' gypsum and reclaimed brick shear walls
- Exterior walls – Brick cladding, 75mm extruded polystyrene insulation, 3 mil vapour barrier, _" moisture resistant gypsum, heavy gauge steed studs, 5/8" type 'X' gypsum. Historic east wall, masonry only, no gypsum wall board.
- Roof – conventional modified bitumen membrane system with 100mm polyisocyanurate foam insulation (HCFC and CFC free), no gypsum – subtracted from extra basic materials
- Assumed 30 MPa concrete with average flyash, floor and roof loads as indicated on structural drawings

Atrium

- Gross floor area = 7.535 m x 65.6 m = 495 m2
- Clad entirely with curtain wall less vestibule roofs
- Atrium roof support structure assumed to be series of trusses constructed from HSS and angle steel members with HSS girts
- Bridges constructed from hollow core concrete slabs supported by steel beams. Additional bridges of poured concrete on metal deck between steel beams and bridges of salvaged timber , which were not modeled.
- Ground floor – hollow core concrete slabs

General (both designs)

- New Windows – aluminium framed, operable, Low-E tin argon filled glazing
- Existing Windows – wood framed, new Low-E tin argon filled glazing only
- Building use = Institutional

Quantities:

- Quantities/areas were calculated from dimensions/quantities as indicated on the structural/architectural drawings. Where no dimensions were indicated, quantities were calculated by scaling the dimensions from the drawings provided.

Assemblies:

- Assemblies (roof, exterior walls, etc.) were modeled as indicated on the architectural drawings or, in the case of the benchmark design, as agreed to in consultation with CCA.

Other Exclusions

- all building site preparation and landscaping;
- all interior finishes beyond partition walls;
- all furnishings.

4.4 Annual Operating Energy Data

Annual operating energy by fuel type estimates were provided by G. Shymko for both the benchmark and actual design buildings. Relative to the benchmark design, the actual design consumes 22% less electricity and 54% less natural gas – a considerable improvement. These data were then entered into the software's primary energy conversion calculator, which also calculates the emissions to air, water and land associated with this fuel use in Winnipeg.

Building	Electricity – kWh/yr	Natural Gas – m^3/yr
Benchmark	2,576,904	646,642
Actual Design	2,017,286	296,868

4.5 Results

This section describes the results of the life cycle assessment for the two project designs on both an absolute and per unit of gross floor area basis. Table 1 below presents the life cycle assessment results for both the benchmark building and the actual project buildings as previously described.

First, to put the embodied results portion of the Table into perspective, we offer the following interpretation. The results indicate that to build, maintain and eventually dispose of a square meter of benchmark building after 75 years in Winnipeg —

- embodies 3.47 Gj of energy and uses 447 kg of raw materials (weighted);
- produces greenhouse gases equivalent to 129 kg of CO2;
- requires 34 cubic meters of air and 31 cubic meters of water to dilute these pollutants to acceptable levels; and,
- results in 34 kg of solid waste.

Table 1
Results: Environmental Impact Profile

Design	**Embodied Energy** Gj	**Solid Wastes** tonnes	**Air Pollution** Critical Vol Measure	**Water Pollution** Critical Vol Measure	**Global Warming Potential** Eq. CO_2 tonnes	**Weighted Resource Use** tonnes
Benchmark – 20,068 m^2						
Embodied Effects	69666	682	684560	622006	2588	8965
Per m^2	3.471	0.034	34.112	30.995	0.129	0.447
Annual Operating Energy Effect	29747	76	726774	56	1566	86
Per m^2	1.48	0.00	36.22	0.00	0.08	0.00
Actual Design – 18,885 m^2						
Embodied Effects						
Adelaide Block	23078	274	260216	4729979	1100	5487
Atrium	4559	80	120325	36698	384	691
William Block	10544	102	127286	70908	528	2412
Princess Block	50871	676	540132	6532259	2572	16497
Design Total	89053	1132	1046503	11369842	4585	25087
Per m^2	4.72	0.06	55.41	602.06	0.24	1.33
Annual Operating Energy Effect	14002	40	340059	26	749	67
Per m^2	0.74	0.00	18.01	0.00	0.04	0.00
Total Life Cycle Effect – 75 yrs						
Benchmark						
Embodied	69666	682	684560	622006	2588	8965
Operating Energy	2231019	5727	54508050	4200	117479	6457
Grand Total	2300685	6409	55192610	626206	120067	15422
G. Total Per m^2	114.64	0.32	2750.28	31.20	5.98	0.77
Actual Design						
Embodied	89053	1132	1046503	11369842	4585	25087
Operating Energy	1050141	3024	25504425	1950	56149	5055
Grand Total	1139194	4156	26550928	11371792	60734	30141
G. Total Per m^2	60.32	0.22	1405.93	602.16	3.22	1.60

These embodied results represent a very basic, generic benchmark design. The benchmark building is to say the least non-descript and may lack elements essential for its designated end-use. For example, a prerequisite for a school is adequate daylighting in all areas of the facility which, given it size, would likely require an atrium or undulating exterior wall profile with larger windows then considered in this assessment. The limited time and scope of this project curtailed developing a more detailed comparative benchmark, and it is our opinion that the current benchmark design probably understates the structural and envelope embodied effects of a typical school on this site, with the result that the embodied effects of the actual design appear greater in comparison to the benchmark than they would be otherwise.

Relative to the benchmark building, the actual campus development embodies more energy and resources, produces more air and water pollution (including greenhouse gases), but produces less solid waste. The higher impacts of the actual development are not surprising in light of the fact that the surface area of the development (3 buildings plus an atrium) is close to 3 times higher that of the single benchmark building discussed above. The lower solid waste for the development can be traced to the reuse of the existing building and significant use of reclaimed on-site materials as well as the use of pre-cast materials, which result in less on-site waste.

To put a more human context on embodied energy results we performed a quick calculation which revealed that the embodied energy of the actual building was equivalent to the annual space heating requirements of 710 R2000 houses located in Winnipeg.

The difference between the annual operating energy results for the actual design and a benchmark design is quite striking, with the actual design achieving a 50% reduction in operating energy. As noted earlier, we have to be somewhat cautious in interpreting this result because the benchmark operating energy estimates were developed based on the three buildings instead of the single benchmark building design that was modelled. As a result, the values for the benchmark are probably overstated, and we have no basis for assessing the extent.

Over the full 75 year expected life of the project, the actual design's total energy use and greenhouse gas releases are about half of that of the benchmark design. The benchmark's air pollution is also higher, but its water pollution and resource use are considerably lower relative to the actual design.

5 Mayo School and Jackson Triggs Winery

5.1 *Introduction*

The Mayo School/Community Centre building in Mayo, Yukon and the Jackson Triggs Winery complex in Niagara, Ontario, are two very different case study buildings, although both buildings are of entirely new construction. The actual designs of both were compared to benchmark reference designs developed as part of the GBC ’02 process.

To simulate the regional location of the two project buildings we used the Toronto regional location for the Jackson Triggs Winery project and the Winnipeg regional location for the Mayo School project. While the Mayo School is actually located in the Yukon, it was determined that, of the six Canadian regional location options in the software, the Winnipeg region offers the best simulation fit from an electricity grid and material transportation perspective.

5.2 *Case Study Buildings Design Summary*

Tables 2 and 3 briefly describe the major design elements for each of the projects and their benchmark counterparts.

As is evident from the tables, the designs and respective benchmarks for both buildings share a large number of common elements. Of the two, however, the envelope design for the Mayo School reflects more significant changes in comparison to the benchmark in order to achieve a higher level of insulation and thus a better performance.

Table 2
Mayo School Material and Dimensional Design Summary

Building Component	Benchmark Design	Actual Design
Gross Floor Area	3220 m^2	3220 m^2
Design Life	80 yrs	80 yrs
Primary Structure	Single storey, traditional light frame wood construction	Single storey, engineered wood light frame construction
Envelope	2x6 wood studs, 140mm fibreglass insulation	Double wood stud wall, 209mm fibreglass insulation
Exterior cladding/ fenestration	Wood shiplap siding / aluminium fixed frame window, Low “E” argon	Wood shiplap siding / PVC operable frame window, Low “E” argon
Roofing system / insulation	Conventional 2-ply Mod. Bit. membrane, 100mm XPS	Conventional 2-ply Mod. Bit. membrane, 250mm cellulose

Table 3
Jackson Triggs Winery Material and Dimensional Design Summary

Building Component	Benchmark Design	Actual Design
Gross Floor Area	3171 m^2	3318 m^2
Design Life	40 yrs	40 yrs (for comparison purposes)
Primary Structure	two storey, 1st fl.- concrete flat plate on column; 2nd fl.- WF/HSS col.&beam with OWSJ floors and roof	two storey, 1st fl.- concrete flat plate on column; 2nd fl.- WF/HSS col.&beam with OWSJ floors with wood space frame roof
Envelope	Conc. Block/steel stud (minor curtain wall section) w/ 150mm rockwool batt and 75mm XPS	Conc. Block/major curtain wall element/ wood stud w/ 50mm XPS
Exterior cladding/ fenestration	Steel cladding, some brick / aluminium fixed frame window, Low “E”	Steel cladding, brick and stucco operable AL frame window, Low “E”
Roofing system / insulation	4-ply BUR, 75mm EPS	4-ply BUR, 75mm EPS

5.3 Data Manipulation and Analysis

The Institute retained the services of JAN Architects to review the GBTool input files, building drawings, and material lists prior to data input into *ATHENA™ 2.0.* Any interpretive discrepancies or missing data were discussed with the assessment leaders. We then developed an estimate of the life cycle embodied and annual operating effects as per some of the measures described in section 3.2.

Excluded from the analysis of each building are interior finishing materials beyond finished gypsum board exterior and interior walls (e.g., floor coverings, doors, etc.) and anything exterior to the immediate building (e.g., landscaping, sidewalks, driveways, etc.).

5.4 Annual Operating Energy Data

S. Pope provided values for the Mayo School operating energy by fuel type via a CPIB estimation procedure. The Jackson Trigg’s operating energy information was provided by Chris Jones who used EE4 simulation software. These annual operating energy data, shown in Table 4, were then entered into the software’s primary energy conversion calculator, which then calculated the emissions to air, water and land associated with the fuel use.

Table 4
Annual Operating Energy by Fuel Type

Building	Electricity – kWh/yr	Fuel Oil – L/yr
Mayo School		
Benchmark	360,170	116,742
Actual Design	750,551	9,807
	Electricity – kWh/yr	Natural Gas – m3/yr
JT Winery		
Benchmark	790,854	145,191
Actual Design	658,566	89,383

5.5 Results

Table 5, below, reports the primary energy, global warming potential, acidification, smog and eutrophication emission results for the actual and benchmark designs for each building. In each case the table distinguishes life cycle embodied effects from operating energy effects. Included in the embodied effects analysis and results is each building’s structure, partitions and envelope materials.

Table 5
Canadian GBC 2002 ATHENA Assessment Results

Building	**Primary Energy** (Gj)		**Global Warming Potential** (Equiv. CO_2 tonnes)		**Acidification Potential** (Equiv. SO_2 tonnes)	
	Actual	Benchmark	Actual	Benchmark	Actual	Benchmark
Mayo School						
L.C. Embodied Effects	8,816	7,883	430	414	5.2	4.3
Annual Op. En. Effects	759	5,486	748	1,566	.6	4.6
Jackson Triggs Winery						
L.C. Embodied Effects	17,718	13,338	999	803	9.6	8.1
Annual Op. En. Effects	10,592	14,398	443	618	6.2	8.9

Building	**PhotoChemical Ozone Potential** (Equiv. O_3 tonnes)		**Eutrophication Potential** (Equiv. PO_3 tonnes)	
	Actual	Benchmark	Actual	Benchmark
Mayo School				
L.C. Embodied Effects	.8	.6	.3	.4
Annual Op. En. Effects	.01	.1	.02	.1
Jackson Triggs Winery				
L.C. Embodied Effects	1.3	.9	.6	.8
Annual Op. En. Effects	.3	.5	.2	.2

Two key findings are evident in Table 5.

1. With the exception of the eutrophication measure, the actual embodied primary energy and emissions are higher than the benchmark levels for both buildings.
2. Both building projects show a marked improvement in annual operating energy for the actual design compared to their respective benchmarks.

When we look behind these results, it is evident that the Mayo School was able to lower its annual operating energy consumption by using a combination of superior envelope design and higher efficiency heating equipment. The envelope design resulted in higher embodied effects compared to the benchmark, but with a significant operating energy payoff. In addition, the difference between the Mayo School’s actual and benchmark operating energy use indicates more than the usual across the board reduction in energy use by type as in the case of the winery (see Table 4). Although electricity use is higher for the actual design compared to the benchmark, heating oil use has dropped sharply. Since electricity generation in the Yukon is almost exclusively hydro based, with little or no global warming gases being produced, the reduced use of oil coupled with a greater reliance on electricity results in an overall reduction in primary energy use, taking account of all of the upstream or pre-combustion effects associated with the different energy forms.

Overall, the combination of a higher performing envelope, fuel switching, and a higher efficiency HVAC system led to a 7-fold decrease in annual operating energy and associated global warming potential. At the same time, the design team prevented too high an embodied effects increase by the use of wood for the structural system and cladding and by judicious selection of other materials. For example, the team substituted cellulose insulation, which has relatively low embodied effects, for extruded polystyrene insulation in the roof.

As shown in Table 6, the embodied energy in the benchmark design for the school is equivalent to 1.4 years of operating energy, while for the actual design embodied energy is equivalent to almost 12 years of operating energy. This is exactly the kind of result one expects to see when an improved envelope design has significant positive effect on operating energy use.

Table 6
Comparative Embodied to
Annual Operating Energy Ratios

Building	Embodied / Op. Energy ratio (yrs)
Mayo School	
Benchmark	1.4
Actual	11.6
JT Winery	
Benchmark	0.9
Actual	1.7

In the case of the Jackson Triggs Winery, the higher embodied effects reflect an overall greater use of materials and a generally higher architectural quality for the actual design compared to the more conventional benchmark design. But the project relies almost exclusively on higher performing HVAC technologies instead of a higher performance envelope to achieve operating energy improvements. Hence, the resulting operating energy savings are more typical, but never the less impressive - a 38% decrease in natural gas use and a 17% reduction in electricity use. In this case, the embodied to annual operating energy ratio changes very little from the winery's benchmark to its actual design.