INTRODUCING ATHENA™ v2.0: AN LCA BASED DECISION SUPPORT TOOL FOR ASSESSING THE ENVIRONMENTAL IMPACT OF THE BUILT ENVIRONMENT

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ABSTRACT
This paper provides an overview of ATHENA, an environmental decision support tool developed for building designers and researchers by the ATHENA Institute. The paper also addresses some practicalities and key data issues to be considered when applying life cycle assessment to buildings. It stresses the importance of accepted research protocols and transparent research processes to ensure equitable treatment of different materials and products, and deals with the issue of ensuring functional equivalence when assessing building products or partial building designs.

INTRODUCTION

There is a growing desire to put the environment on an equal footing with cost and other conventional design and product performance criteria. And while the task is by no means simple, life-cycle assessment (LCA) has been generally accepted as the best way to systematically understand environmental impacts and ultimately compare alternative materials, components and services (Cole & Larsson, 96). To date, efforts to reduce the environmental impacts of buildings and construction have focused primarily on making them more energy efficient, a valid priority given the huge potential for improving a building's total life cycle environmental impacts through design initiatives targeting the usage phase. However, the usage phase is not the entire environmental story for buildings. A recent study of nearly 500 sectors in the US economy found that the construction sector produces the most CO2 emissions through the manufacture, transport and use of materials. At about 300 million metric tons, the sector creates more upstream emissions than the direct total fossil CO2 emissions of all US state and local government electric utilities (Norris, 1999).

Another study comparing embodied and operational energy use in Canadian office buildings indicated embodied energy intensities ranging up to an equivalent of more than 20 years of operating energy use. The study also confirmed that the embodied energy of buildings can be significantly influenced by material selection or other design decisions (ERG, 1994).

Over time, the environmental burdens of buildings are likely to gain further relative significance as we shift our attention to other issues such as toxic releases, materials flows, and waste. But even if we keep the focus on energy consumption, the message is clear:

1. upstream environmental impacts of buildings and construction are highly significant;
2. they offer important opportunities for environmental improvements; and

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3. they therefore warrant careful attention during building design and material selection (Norris, 1999b).

Understanding the significance of environmental design and gaining an LCA perspective is laudable. In practice, however, designers and engineers are seldom paid for the extra time and effort to be green and, in any event, they should not have to become LCA experts to incorporate environmental decision-making in their design process. We therefore have to make it possible for designers and others to readily access LCA-based answers without having to actually undertake LCA, we especially have to make sure they have access to current, reliable and comparable environmental Life Cycle Inventory (LCI) data.

The Athena Sustainable Materials Institute is dedicated to helping the building community meet environmental challenges and improve environmental performance through the provision of data, tools and services. The principal tool under continual development is the Athena model — a practical, easy-to-use decision support tool that provides high quality environmental data and assists with the complex evaluations required to make informed environmental choices during the conceptual design stage of a project. The ultimate goal is to encourage the selection of material mixes and other design options that will minimize a building's potential life cycle environmental impacts and foster sustainable development — an essential element in an integrated design process.

THE ATHENA™ DATABASES

The Institute has developed a set of regional North American life cycle inventory (LCI) databases for key building products, covering 90-95% of the structural and envelope systems applicable to typical commercial, institutional, light industrial and residential buildings.

These databases include various wood, steel and concrete products used in structural applications, cladding products and systems, insulation and roofing materials and systems, gypsum wallboard and related finishing materials and selected glazing and window framing options.

To augment the above product and system LCIs, the Institute has also developed databases for energy use and process related emissions for on-site construction, maintenance and replacement and transportation effects for discrete structural and envelope materials and assemblies applicable to a wide cross-section of building and occupancy types. The Institute has also developed building demolition and final product disposition life cycle effects for various materials.

THE ATHENA™ SOFTWARE

The ATHENA™ v2.0 software is a conceptual design simulator that integrates the Institute's databases so that architects, researchers and policy analysts can easily assess the relative environmental effects of geographically sensitive design options for all, or part of building over its complete life cycle. Some of the specific features of the model include:

1. the ability to model the building's complete structure and envelope (claddings, insulation, gypsum wall board, and roofing and window systems – over 900 possible assembly combinations);
2. the ability to model maintenance and replacement life cycle effects based on building type, location and a user defined life for the building;
3. a calculator to convert operating energy to primary energy and emissions to allow users to compare embodied and operating energy

environmental effects over the building's life (requires a separate estimate of operating energy as an input);
4. an "end-of-life" module, which simulates demolition energy and final disposition of the materials incorporated in a building;
5. a context sensitive help facility in place of a users' manual; and,
6. the capability to model Canadian and US regional locations.

Example Simulation Results

ATHENA's results are presented in various ways and levels of detail to meet the needs of different types of users. A researcher wanting detail can see the results by specific energy forms or waste substances, by life cycle stage and by assembly type. An architect may only be interested in tabular or graphical displays of summary measures or characterizations by building assembly and for the total design. The model also allows the user to make direct comparisons among alternative designs.

Figure 1 shows six comparative summary measures generated by ATHENA for three different designs of a custom 2400 sq. ft. single-family home for the Toronto market over a sixty-year expected life span. While the three home designs are similar in outward appearance, size and divided living area, they are markedly different in terms of the types and quantities of materials used. One is designed using softwood lumber and engineered wood I-joist framing, the second incorporates light frame steel for its primary wall and floor structure, and the third design uses insulated concrete forms (ICF) for the basement and exterior walls as well as a HAMBRO floor system.

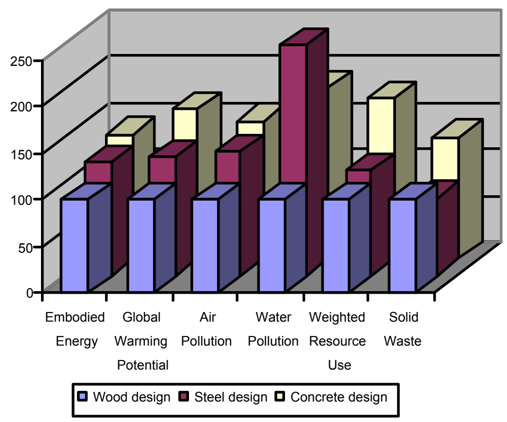
Our environmental analysis was limited to the structure and envelope components that differed across the three designs, with common elements excluded. For example, the three house designs share the same wood truss roof system and shingle finish, windows and exterior cladding and these assemblies and elements were excluded from the study. While the study considered the full life cycle of each design, the structural and basic envelope components (insulation and gypsum board) dominated the comparison as these elements are essentially maintenance free and unlikely to be altered or replaced because of durability concerns during the life of a residential structure. Although the material effects during the occupancy stage were relatively minor they are understated, because of the exclusion of the exterior finishes (e.g., shingles, cladding and windows). The assessment also considers the "end-of-life" stage. The higher mass of the concrete design required relatively greater energy to demolish and dispose of then either the wood or steel designs, but because a high percentage of steel is typically recycled, the steel design had the lowest "end-of-life" impact of the three designs.

The results shown in the figure for the steel and concrete designs have been normalized using the wood design results as a base case. This is one of several ways in which ATHENA allows users to compare results for different designs, including comparison with past designs saved in a library. It is a particularly useful comparison format because it provides a simple overview of how the designs compare across disparate measures, without regard for absolute values or units.

We always advocate caution in interpreting results like these because the convenient labels on alternative designs can be misleading. The 'wood', 'steel' and 'concrete' designations reflect the dominant materials for the structural systems, but all of the designs incorporate a mix of materials and the results are not necessarily a function of the dominant material. As well, there are usually trade-offs among the different measures and the absolute numbers are much less important than the relative numbers when making design choices. Seldom is one system clearly so green that it totally dominates.

We should also comment on the resource use and solid waste results, both of which are measured on a mass basis. While mass is generally the preferred measure in LCA, volume measures would give a different picture, especially for elements like concrete construction waste which has high mass and low volume compared to wood waste. ATHENA may in the future show results both ways, but the user will have to decide which measure is more important and that in turn will depend partly on the disposition of the different kinds of waste in the relevant jurisdiction.

Figure 1
Results Summary: An Example of Benchmarking



ENSURING FUNCTIONAL EQUIVALENCE

When we talk about the fairness of design comparisons, we are really talking about ensuring functional equivalence — a difficult problem for systems as complex as buildings.

The principle that products have to be compared on a functionally equivalent basis is well understood when it comes to LCA of typical industrial or consumer goods. We have to similarly ensure equivalence in terms of such criteria as loads, spans, space enclosure and surface coverage when we compare building products or assemblies. However, those kinds of criteria do not ensure true equivalence in the context of a building life cycle.

To meet a true equivalence test for buildings we have to take account of all the relevant properties or attributes of individual products and components. We also have to take account of their interrelationships over the life of the building. In fact, we believe true equivalence can only be ensured at the level of a complete building design.

For example, concrete and steel structures have different thermal mass and conductivity implications which could affect operating energy. Similarly, two different systems of beams and columns of equal load bearing capacity could have such weight differences that significantly more concrete would be required in the footings for one compared to the other. Differences like these could certainly affect the choice of design options from an environmental perspective and should be reflected in a LCA.

For example, in the case of the three house designs, we noted that the fully insulated basement living space provided by the ICF system afforded a greater level of 'comfort' relative to the wood and steel designs which only stipulated code levels of insulation to the frost line in the basement. Since we were not doing an operating energy simulation which would capture life cycle differences in operating energy use, we were concerned that the designs were not functionally equivalent. The design team therefore decided to insulate both the wood and steel designs to the same level as the ICF system. As a result, the final designs for the wood and steel houses have thicker concrete basement walls than the ICF system and both have interior studs down to the basement floor to hold R19 batt insulation.

But for the above grade exterior walls, subsequent analysis indicates that the steel design has a lower effective R value than the wood and concrete designs despite a combination of rigid and batt insulation that provides a slightly better nominal R value for the steel compared to the other two designs. So it is likely that operating energy will still be somewhat higher for the steel design — an example of how difficult it can be to achieve true functional equivalence in comparisons of such complex systems as buildings, and of the importance of assessing the full life cycle, including operating energy.

THE LCI DATA IS CRITICAL

Basic LCI data is at the heart of any LCA. The quality of that data determines the quality of the final results, whether those results are presented as simple summary aggregations, as full impact assessments or as some type of ecological score.

We believe the designer of any LCA tool aimed at the lay user as opposed to the LCA practitioner has to take very great care in the LCI phase. If we are going to suggest that architects use a tool to assess the relative environmental effects of different combinations of materials, or other design options, we have to be very sure that all products and materials are treated in a sufficiently comprehensive and consistent manner. In other words we have to ensure a level playing field. If we do not, we may unfairly discriminate against individual products and lead the architect to pick exactly the wrong design option from an environmental perspective. For tools intended for use at a conceptual design stage, it is especially important that the LCI data be representative of industry averages, in other words of the supplier pool from which final purchase decisions will be made.

The LCI databases in ATHENA are locked and the user cannot modify, replace or add data. This puts an onus on the Institute to make the data transparent and to ensure its quality, consistency and comparability. In fact, carrying out the life cycle inventory studies is the most costly and time-consuming part of the Institute's work. All users of ATHENA have the option to purchase the various life cycle studies underlying the model.

A COMMENT ON INTEGRATED DESIGN

The house example results are typical of the output provided by Athena, with results characterized and grouped in a set of summary measures. We are not alone in being cautious about advancing beyond this characterization step to valuation and single number scores. Valuation and scoring can be valuable if used carefully to meet defined objectives and with congruent normalization and weighting. But it can otherwise lead to anomalous, or even nonsensical results. For now, we leave it up to the user to make trade-offs among the disparate measures.

But this obviously complicates the process of integrated design where the environmental effects must be balanced against cost, durability, indoor health and other criteria. And there are no easy answers.

One solution would be to convert environmental effects into monetary terms by estimating either the costs of ultimate health impacts or of remediation. Considerable work has been done by researchers to estimate these externality costs, to use the economist's term. However, there is still a long way to go before organizations like ours can simply adopt and incorporate estimates into software without jeopardizing the reliability of the software as decision support tools. Nor are we comfortable, as indicated above, with eco-point or eco-indicator systems that depend heavily on subjective weighting to develop single scores that might be combined with other criteria in a multi-attribute decision analysis.

So while we applaud efforts to optimize in an integrated design framework, we must add a cautious note that there is still a long way to go before the environmental element can be readily factored into the equation.

REFERENCES

Cole, R. J., 1993 'Embodied Energy and Residential Building Construction', Proceedings: Innovative Housing '93, Volume 1: Technology Innovations, pp. 49-59.

Cole, R. J. and Larsson, N., 1996.Green Building Challenge '98: A General Framework for Building Performance Assessment.

Environmental Research Group, 1994 "Life-Cycle Energy Use in Office Buildings", School of Architecture, University of British Columbia, research report prepared for the Athena Sustainable Materials Institute, August 1994.

Norris, G. A., 1999 Direct and Upstream Emissions of Carbon Dioxide from Fossil Fuel Combustion, research report submitted to the National Renewable Energy Laboratory by Sylvatica.

Norris, G. A., 1999b Systematic/Holistic Application of Environmental Life Cycle Assessment to Building Material Selection, research report submitted to BNIM Architects by Sylvatica, July 1999.