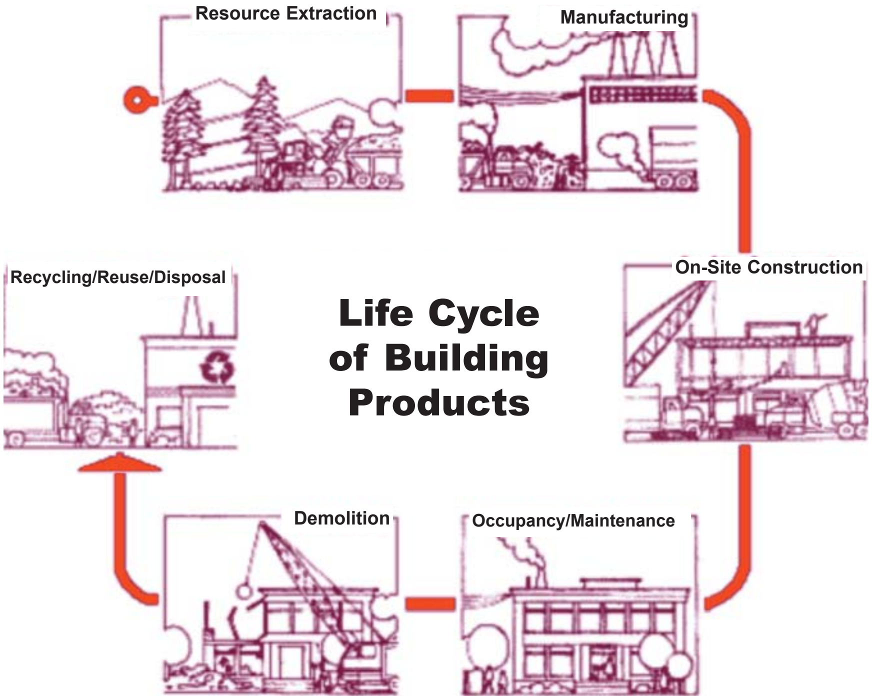
SUSTAINABLE BUILDING: A MATERIALS PERSPECTIVE

by Wayne Trusty

ABSTRACT



Whole building assessment systems like BREEAM Green Leaf, LEED™ and Green Globes rightly place considerable emphasis on the selection of green materials or products as an important aspect of sustainability. Architects are clearly concerned about this topic, but are increasingly becoming aware of the time and resources used in the search for reliable information. This article will assist by highlighting information sources and tools that can help in the search. It will also discuss the relative importance and environmental merits of structural and envelope materials. But perhaps more important will be an effort in the article to step back and look at the broader questions of what constitutes 'green', and what sustainability means in the context of building design decisions and material choices.

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OBJECTIVES

After reading this article, you should have a basic understanding of the following topics:

1. different types of decision support tools, their purposes and appropriate uses;
2. the systems aspect of building product assessments, and the related problem of ensuring true functional equivalence in product comparisons;
3. the role of Life Cycle Assessment (LCA) and its future integration in whole building assessment tools;
4. major environmental criteria for selecting green building materials;
5. the most significant material choices from an environmental perspective;
6. trade-offs and relative environmental performance of materials and systems across a spectrum of performance measures; and
7. how LCA can inform the design process with specific reference to residential case studies using the Athena *Environmental Impact Estimator*.

INTRODUCTION

Designing, constructing and operating environmentally friendly buildings can be a lot more complex than it seems, especially when it comes to materials selection. We would all like simple measures or rules of thumb that would make the selection process easy, but they are hard to come by, if they exist at all. The reality is that we are constantly forced into a balancing act, trading off a good effect here with a not-so-desirable outcome there.

The Athena Institute, a not-for-profit organization dedicated to furthering environmental sustainability, focuses on life cycle assessment (LCA) of a range of building materials and on the use of that data in its *Environmental Impact Estimator* software. The *Estimator* is intended to let architects, engineers and researchers assess the environmental implications of building designs at an early stage in the project delivery process. It is designed to meet the needs of professionals who do not have the time and resources to pursue the details without oversimplifying. Here, we can use results from the tool to shed some light on the materials selection issue. Before we do, it is useful to first explain briefly what LCA is, and to then introduce a simple classification system that helps position the *Estimator* and other tools in terms of their focus, intent and use in various phases of a project delivery process.

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ATHENA 2.0 BETA V3.1 Internal
    House Design 1 (553.35 GigaJoules)
        Floors and Roofs (181.74 GigaJoules)
            Light Frame Wood Trusses (181.74 GigaJoules)
                    garage roof (34.64 GigaJoules)
                    main roof (135.16 GigaJoules)
                    Secondary roof (11.94 GigaJoules)
        Foundations (92.31GigaJoules)
            Concrete Footing (29.70 GigaJoules)
                    10x24" footing (29.70 GigaJoules)
            Concrete Slab on Grade (62.61 GigaJoules)
                    primary slab-on-grade (62.61 GigaJoules)
        Walls (279.29 GigaJoules)
            Concrete Block Wall (273.38 GigaJoules)
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Select Summary Measure

Energy Consumption
Solid Waste Emissions
Air Pollution Index
Water Pollution Index
Global Warming Potential
Weighted Resource Use

Figure 1: Sample of Athena's Estimation Software Analysis

Life Cycle Assessment

Put simply, LCA is a methodology for assessing the environmental performance of a product over its full life cycle, often referred to as cradle-to-grave or cradle-to cradle analysis. Environmental performance is generally measured in terms of a wide range of potential effects, such as the following:

- fossil fuel depletion;
- other non-renewable resource use;
- global warming potential;
- stratospheric ozone depletion;
- ground-level ozone creation (smog);
- nutrification/eutrophication of water bodies;
- acidification and acid deposition (dry and wet); and
- toxic releases to air, water, and land.

All of these measures are indicators of the environmental loadings that can result from the manufacture, use and disposal of a product. The indicators do not directly address the ultimate human or ecosystem health effects, a much more difficult and uncertain task, but they do provide good measures of environmental performance on the premise that reducing any of these effects is a step in the right direction.

In LCA, the effects associated with making, transporting, using, and disposing of products are referred to as 'embodied effects', where the word embodied is not meant to imply true physical embodiment, but rather attribution or allocation in an accounting sense. In the building community, the tendency is to refer primarily to 'embodied energy', but there is a wide range of embodied effects, as implied by the list of indicators. All of the extractions from, and releases to, nature are embodied effects, and energy itself involves a wide range of embodied effects associated with the production and transportation of energy (known as pre-combustion effects).

In the case of buildings, the energy required to operate a building over its life greatly overshadows the energy attributed to the materials used to in its construction and maintenance. However, for other embodied effects such as toxic releases to water, effects during the resource extraction and manufacturing stages greatly outweigh any releases associated with building operations.

It is also important to note that the LCA of a product should take account of the production and use of other products required for cleaning or maintaining the product during its use phase. For example, we should take account of the paints required to maintain some types of wood cladding, and of the cleaning products required to maintain various kinds of flooring. We must similarly take account of the repair and replacement of individual products through the building life cycle.

The final point to note about LCA is that it is not the same as life cycle costing (LCC). The two methodologies are complementary, but LCC focuses on the dollar costs of building and maintaining a structure over its life cycle, while LCA focuses only on environmental performance. Performance is measured in the units appropriate to each emission type or effect category. For example, global warming gases are characterized in terms of their heat trapping effects compared to the effects of CO_2, and global warming potential is then measured in equivalent tonnes of CO_2.

A Tool Classification System

This simple tool classification system, developed by the Athena Institute, contemplates three main levels of tools.

Level 1 tools focus at the individual product or simple assembly level (e.g., floor coverings or window assemblies) and are used to make comparisons in terms of environmental and/or economic criteria. These are probably the most common tools. *BEES* and *GreenSpec Directory* may be especially relevant for architects:

- *BEES* is an LCA based software tool developed by the U.S. National Institute of Standards and Technology;
- *GreenSpec Directory* is a guide to environmentally preferential building products produced by Building Green (the publishers of Environmental Building News).

BEES is designed to make product-to-product comparisons based on LCA and LCC data. It provides a full set of environmental indicators of the kind listed earlier, and also allows environment versus cost comparisons, using a weighting system to combine disparate environmental measures into one score that can be charted against cost.

GreenSpec Directory is provided in book form and through an on-line web site subscription. It provides detailed product listings for more than 1,650 products in 250 categories, organized according to the CSI *MasterFormat*™ system. The Directory provides detailed information to help readers understand the environmental merits of individual products based on a set of criteria developed by the publishers. GreenSpec also provides guideline specifications for each product category, indicating the benefits, drawbacks, environmental considerations, and generally what to look for in a green product within a given category.

One could argue that labeling systems like the Environmental Choice program, operated by Terra Choice, and various forest certification systems are also Level 1 tools. The caution is that many labeling programs focus on single attributes, or performance measures (energy use or recycled content, for example), and may therefore be misleading when they convey a 'green' label. The product in question may indeed be excellent in terms of the criteria selected for the evaluation, but that does not necessarily mean it would score well in a full LCA, or in a system that takes more attributes into account.

Other Level 1 tools used in North America (e.g., SimaPro, TEAM, and GaBi) are intended more for the use of LCA practitioners and are therefore of less interest here.

Level 2 tools focus on the whole building, or complete assemblies, providing decision support in specific areas of concern such as life cycle costs, operating energy, or life cycle environmental effects. They are data-oriented and objective, and apply from the conceptual through detailed design stages. The Athena software fits in this category, as do energy simulation and life cycle costing tools.

As the only tool of its type in North America, Athena's *Environmental Impact Estimator* is particularly relevant here because it is the only Level 2 tool that assists with material selection in the context of life cycle assessment of an entire building. Rather than dealing with individual products, it focuses at the level of whole buildings or complete building assemblies (walls, floors and roofs, for example) and therefore captures the systems implications of product selections related to a building's structure and envelope. The *Estimator* and *BEES* are complementary, with the *Estimator* more appropriately used at the conceptual design stage, and *BEES* at the specification or procurement stage of project development.

The *Estimator* also allows the embodied effects of materials production and use, including maintenance and replacement over an assumed building life, to be compared to and merged with estimates of operating energy use that have been separately developed using energy simulation software. As a result, operating energy emissions and pre-combustion effects (i.e., the energy and emissions associated with making and moving energy) are taken into account.

Level 3 tools are whole building assessment frameworks or systems that encompass a broader range of environmental, economic and social concerns or issues considered relevant to sustainability. They use a mix of objective and subjective inputs, leaning on Level 2 tools for much of the objective data—energy simulation results, for example. All use subjective scoring or weighting systems to distill the information and provide overall measures, and all can be used to inform or guide the design process.

LEED and BREEAM Green Leaf are currently the best-known Level 3 tools in Canada, with Green Globes, a derivative of BREEAM Green Leaf, rapidly becoming established as the successor to its parent. Currently available Level 3 tools may apply to new projects, to existing buildings, and to major renovations or retrofits. Some require external auditors, and most yield certificates or labels indicating a building's performance. They can be used for a wide range of building types, from single and multi-family residential to commercial, institutional and light industrial.

MATERIALS FROM A SUSTAINABILITY PERSPECTIVE

If we turn to specific materials, the answers are seldom as clear-cut as we would like. We would all welcome rules of thumb or labels to tell us which products are truly green, taking all factors into account over the whole life cycle. The unfortunate fact is that we can't get those answers without formal life cycle assessment or some equally thorough approach. In the absence of that kind of information, we should regard seemingly easy answers with caution. For example, the production and ultimate disposal of resins used in the manufacture of plastic wood have to be taken into account if that product is to be considered as one of the "better alternatives" to wood treated with chemicals, or to wood from old growth forests, as may be suggested in manufacturer's claims or well-meaning articles.

This section highlights some key factors to bear in mind when making product comparisons or selections, and provides a basis for setting priorities when tackling the product selection problem with a view to minimizing a building's environmental footprint.

Maintaining Functional Equivalence

We should be especially careful to ensure that product comparisons are truly apples-to-apples comparisons. In LCA-based comparisons, we use the term 'functional equivalence' when referring to the problem of ensuring that two or more products provide the same level of service. Ensuring functional equivalence in product comparisons is not as easily accomplished in building applications as might be supposed. The problem is that the choice of one product may lead to, or even require, the choice of other products. Consider the following examples:

- the choice of wood, steel or concrete structural systems will likely influence, or even dictate, the choice of insulation materials;
- an above-grade structure using high mass materials may require more concrete in footings than a lighter structural system; and
- a rigid floor covering may require a different substrate than a flexible floor covering.

These are just a few examples of situations where product comparisons should take account of other material-use implications of the alternatives. In other words, comparisons should be made in a building systems context rather than on a simple product-to-product basis. Even though two products may appear to be equivalent in terms of specific criteria like load bearing capacity, they may not be at all equivalent in the sense of true functional equivalence.

In a similar vein, we should be careful to take account of all the components that may be required during building construction to make use of a product. Mortar and rebar go hand in hand with concrete blocks, just as fasteners, tape and drywall compound are integral to the use of gypsum wallboard.

Not all products pose a functional equivalence problem to the same degree. In general, product-to-product comparisons are more likely to be misleading when dealing with structure and envelope materials, where the systems context is key. As we move to interior finishes, fit-out products and furnishings, product-to-product comparisons are more realistic. For example, resilient or flexible floor coverings can readily be compared to each other as long as we take account of installation materials, cleaning products, expected service life, and what happens at the end of a product's life. Even window systems, although part of the envelope, are typically delivered to a construction site as pre-assembled components that can be compared to each other in terms of thermal performance or other criteria, without too much regard for broader systems implications.

In short, we can think in terms of a continuum from very systems oriented products at the structural end of the scale to more stand-alone products at the interior fit-out end. The task is to exercise caution and judgment about whether any given comparison is legitimate.

Conventional Wisdom and the Proxies Problem

Most, if not all, of the Level 3 whole building assessment tools do an admirable job of fostering and facilitating integrated design practices and a holistic approach. These systems generally capture the complicated, web-like relationship between a building's location, construction and operations and its impacts on human health and the environment, a relationship that is similar to the complexity of ecological systems in nature where nothing functions or changes without resonating in another part of the system.

However, the systems are not as robust when it comes to guidelines or credits for materials selection. 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. We believe that challenge must ultimately be met by a better integration of LCA techniques and LCA-based decision support tools in whole building rating and certification systems, a goal that all of the system developers are working toward.

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, conceptions 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 ends and means, with the means becoming objectives in their own right to the possible detriment of environmental performance.

For example, granting credits for recycled content in products presumes that using 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. There is no doubt that recycling can save landfill space, but the process of recycling a given product may take more energy and adversely affect air or water 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 and 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. Moreover, a focus on recycled content promotes the use of highly recycled materials like steel over potentially more benign materials, such as wood or perhaps concrete. At the same time, promoting highly recycled materials like steel may do little for the cause of environmental stewardship because recycling is already a fundamental part of that industry's structure and operations, and is driven primarily by industry economics. The bar would have to be set very high indeed to promote more recycling than would occur anyway.

There are other examples of conventional wisdom or proxies taking the place of true environmental measures. One worth noting is the emphasis on local purchasing, with the presumption that local purchasing will reduce environmental footprints because of the reduced transportation requirements. That may indeed be the case if we know that the local manufacturer of a product has an efficient plant in terms of energy, water and resource use, and is at least an acceptable performer in terms of toxic or other releases to the air, water and land. We also have to ask whether a local supplier is drawing inputs from very long distances or from poor environmental performers. And, finally, we have to recognize that different transportation modes have different environmental implications per tonne kilometer of transportation service. Local purchasing should be defined in terms of short distances for suppliers entirely dependent on truck transportation, longer when rail is used, and much greater distances for water transportation.

Setting Materials Selection Priorities

Early conceptual design decisions lock in a significant percentage of the initial material-related environmental effects of a building—some suggest as high as 80 to 90% in the case of office buildings. The reason for this is that the early decisions tend to deal with the fundamental structural and envelope elements, which are typically the highest mass elements in a building, with significant manufacturing and transportation impacts. Deciding among various structural, cladding, and roofing options also has implications for foundations and the use of other materials as discussed earlier.

It makes sense, then, to assign a high priority to the environmental implications of material choices at the outset of the design process, rather than waiting until the specification or procurement stages, as is too often the case. At the same time, the basic structure and envelope materials are not the only ones that deserve careful attention.

To help with the process of setting priorities and assessing options, it is useful to distinguish two main types of embodied effects. In the application of LCA to buildings, we use the term <u>initial embodied effects</u> for the effects associated with the manufacture, transport and installation of all materials used to construct the building. The subsequent materials implications of maintenance and replacement activities throughout the operating life of a building are referred to as <u>recurring embodied effects</u>. We could add a third category, <u>final</u> or <u>end-of-life embodied effects</u> to cover the demolition and disposal effects when a building is finally demolished. However, although these effects can be important and are therefore included to some extent in the Athena software and other tools, they are highly speculative given that most buildings constructed today are unlikely to be demolished for several decades, if then.

If we focus first on initial embodied effects, the importance of high mass materials comes to the fore, as has been highlighted by research undertaken in the UK. For example, based on mid-90's studies, Nigel Howard reports that the following materials account for almost all of the embodied energy and other environmental effects of building construction in that country. [1]

- Aggregates
- Concrete
- Bricks
- Wood
- Steel
- Plaster
- Plasterboard

In a 1994 study for the Athena project, the Environmental Research Group at the University of British Columbia School of Architecture estimated that structural and envelope systems, as well as related on-site construction, accounted for about 60% of the materials-related (i.e., excluding site work) initial embodied energy of a steel-framed, three story, 4620m^2 generic office building with underground parking. [2] The envelope (walls, glazing and roof) was the most dominant of these elements, accounting for almost 30% of the initial embodied energy, not counting related on-site construction. However, electrical, mechanical, plumbing and conveyance services accounted for almost as much initial embodied energy as the structural system (24%).

A more recent Building Research Establishment Ltd. (BRE) study indicates that the external walls, roof, cladding and ground floor account for more than 60% of the materials-related environmental impacts of a typical UK house over an assumed 60-year life (i.e., taking account of both initial and recurring effects). [3]

BRE has also calculated the typical embodied environmental impacts by constituent elements for a number of generic building models, looking at both initial and recurring effects. [4] It is notable that, for a typical office building, floor finishes were estimated to account for about 40% of total lifetime embodied building impacts, by far the largest of any element. This finding was based on the selection of wool/nylon-mix carpet with foam backing/underlay as typical for commercial buildings. The high impacts reflect the fact that carpets are replaced frequently in commercial buildings, as often as 12 times over a 60-year building life. However, BRE estimates that substituting a carpet with recycled rubber crumb or natural fiber underlay can reduce the overall impacts of floor finishes by up to two-thirds.

The structural systems (superstructure and upper floor structures) have the next largest lifetime impact, accounting for 15% to 20% of the total, although this number would be very much higher if the floor covering impact were reduced or excluded from the calculation. Raised access floors were also found to be significant, accounting for 12%.

There are other materials that have significant recurring embodied effects that should be taken into account. For example, we should pay close attention to recurring effects for any products that require painting or staining, such as some kinds of wood siding and gypsum board, products that have relatively frequent replacement cycles, such as vinyl window sets and roofing, and materials such as resilient flooring that may require the use of specific cleaning products.

THE RELATIVE ENVIRONMENTAL MERITS OF MATERIALS

Buildings are a complex mix of materials and the task is to use the materials in the best combination while meeting all of the durability, aesthetic, cost and other design criteria. Deciding among materials usually involves trade-offs that reflect the full range of manufacturing, use and disposal effects. To understand some of the trade-offs, it is useful to look briefly at the main structural materials—wood, steel and concrete—which can account for a sizeable proportion of initial embodied effects.

Most studies, including our own, support the view that wood building products are relatively benign. In fact, they can have a positive global warming effect to the extent that carbon dioxide sequestrated by growing trees remains locked up in the building products for a long time. The environmental issues tend to centre on the location from which timber is extracted and harvesting practices, with the result that assessment systems such as LEED offer credits for the use of certified wood.

Steel offers high post-industrial and post-consumer recycled content, resistance to pests, and high recyclability. Its manufacture, however, requires high energy input and can result in significant levels of water pollution, although the industry has made tremendous strides over the past 10 to 15 years in reducing emissions to water. The ultimate significance of the high energy use depends in part on the energy forms used directly or to generate electricity, especially for the 'mini-mills' that use electric arc furnace technology.

Concrete is a particularly important part of this discussion as it is the most widely used of all construction materials. At the same time, it is a material that seems to be subject to an unusual level of myth and misunderstanding among members of the green building community, and therefore deserves a somewhat more detailed discussion.

Concrete is typically made from locally available and abundant raw resources, with aggregates accounting for a large proportion of the total mass of concrete. The extraction and processing of the basic raw materials is relatively benign, with environmental concerns focused on the high levels of carbon dioxide released during the manufacturing of cement. These CO_2 releases are unquestionably high. However, it is important to recognize that cement is just a component of concrete, accounting for roughly 7 to 15% of the mass of concrete, depending on the strength. Concrete is the building material, and cement is just one ingredient in the recipe, a critical distinction that is too often ignored. Concrete is certainly not as CO_2 intensive, and therefore detrimental, as often presumed.

In addition, we should be clear that, depending on the efficiency of the cement kiln, more than half (and often considerably more) of the CO_2 releases from cement manufacturing are 'process emissions': they are a result of the calcination process through which carbon is driven out of limestone, and are not the result of fuel combustion. In fact, the same chemical processes that result in CO_2 releases can result in the capture of other fuel combustion emissions, such as sulphur dioxide and nitrogen oxides. The cement industry has been very successful in improving fuel efficiency and reducing emissions in recent decades, but there is little the industry can do about the constraints imposed by nature. Limestone is an abundant naturally occurring resource that can be converted into a very useful building material; to do so, however, requires some unavoidable chemical reactions.

The green building community turns to the use of fly ash as a substitute for Portland cement in the concrete mix as the route to making concrete a more environmentally friendly material. But again there are misconceptions about the nature and use of fly ash. Fly ash comes from power plants that burn coal, and not all fly ash is created equal. It depends, for example, on the type of coal burned, the efficiency of the furnace burning the coal, and the emission control technologies in place. Since the making of concrete is essentially a chemical process, the exact make-up of fly ash can be a critical factor in the mix, and can have a direct bearing on the amount of substitution of fly ash for Portland cement that is practical in a given situation. As a result, substitution at levels above 25 to 35% requires very careful batch testing of the concrete. We have worked on buildings that went to the 50% level, but testing is critical or serious problems can arise. Substitution levels in the order of 60% or more can be achieved through the replacement of Portland cement by blast furnace slag, a waste from steel production that is itself a cementatious material if appropriately treated at the steel plant.

Some cement and concrete industry representatives argue that the use of fly ash is a short-term expedient that helps solve a fly ash disposal problem, and should not be seen as the route to making concrete green. One reason for this viewpoint is that fly ash is only available because of the generation of electricity in coal-fired stations; the more fly ash is demanded, the greater the pressure on supply. The industry does not want to be seen as promoting the generation of electricity by less environmentally preferable methods in order to produce fly ash. In addition, fly ash with appropriate characteristics is not available in all markets and may therefore have to be transported a long distance when specified.

The people advancing these arguments contend, with some justification, that concrete is already a desirable product for reasons such as those mentioned earlier. They also contend that the industry should continue its ongoing quest for improved energy efficiency and for improved production processes generally. Whatever the ultimate answers, this is one more of the many illustrations of the complexity of the 'green materials' debate. One could readily write as many paragraphs about the use of bamboo, agricultural products, or other high profile 'green' alternatives.

To conclude this section, it is worth underscoring the point made earlier: buildings comprise a myriad of materials and the task is to use each to its best advantage, and to optimize around the full life cycle at the whole building level. This task, in turn, requires a focus on environmental implications at the earliest possible stage in building design.

LIFE CYCLE EMBODIED VERSUS OPERATING EFFECTS

So far, the focus has been on initial and recurring embodied effects of materials, the main subject matter of this article. But we should at least briefly consider how the embodied effects compare to, and interrelate with, operating effects.

As a start, it is important to highlight the fact that there is a wide range of embodied effects. As mentioned earlier, the tendency is to focus on embodied energy and to then compare it to operating energy. The inevitable conclusion is that operating energy is so much greater over the life of a building that it should greatly overshadow any concerns about embodied energy. In fact, some argue that we should not even concern ourselves with the embodied side.

However, embodied effects go well beyond energy to include a wide spectrum of emissions to air, water and land. Solid wastes are generated during the resource extraction, manufacturing and on-site construction stages of the life cycle; significant air emissions are generated during all of the intermediate transportation steps; and toxic releases to water and air are almost entirely a function of product manufacturing as opposed to building operations. Moreover, energy itself requires energy and results in emissions during its production and transportation. In other words, we need to take account of the embodied energy and other effects associated with energy. The energy and associated emissions required to make and move energy are referred to as pre-combustion effects.

To the extent possible, we should consider and balance all of these effects throughout the full life cycle. And we should bear in mind that material choices directly influence the operating effects, including energy use (e.g., the thermal properties of envelope materials). When we take a full life cycle approach, we may find that accepting a penalty in one stage of the life cycle, or with regard to specific measures such as initial embodied effects, may yield overriding benefits. The following case study of embodied and operating effects for a house of 1970s vintage versus an R2000 design makes the interrelationships clear.

A Case Study in Sustainable Housing Development

The Athena Institute undertook a benchmarking study for Natural Resources Canada (NRCan) comparing the environmental performance of various single-family home designs as typically built in Canada from the 1970s through to the present. The results of this study make it clear that both the typical 1970s home and the more modern R2000 home embody significant environmental effects; R2000 homes, however, display greatly improved operating energy performance through their life cycle. Although achieving this improvement requires some additional materials (insulation, for example), and as a result incurs higher embodied effects, these increased effects are modest compared to the life cycle gains of R2000 homes.

The work was part of a long-term NRCan research project to improve the sustainability of Canadian housing by a factor of "4" initially, and ultimately by a factor of "10". The first step was to benchmark typical Canadian housing to establish a reference from which improvement could be gauged. The focus of the Athena Institute's work was on the embodied environmental life cycle effects associated with the framing and envelope materials of a custom, single-family home for the Ottawa market. The Institute's environmental assessment concentrated on the effects of manufacturing, transporting and installing the "as built" initial structure, partitions and envelope components, as well as the effects of maintenance and replacement over an assumed 30-year life span for the case study homes. NRCan staff separately assessed the operating energy use.

For the embodied effects analysis, building site preparation and landscaping, interior finishes beyond initial gypsum board installation, furnishings, and "end-of-life" disposition of the houses were excluded from the assessment. The reported results therefore provide a conservative estimate of the total life cycle environmental impacts of constructing and maintaining a home over its life compared to an assessment with all such factors taken into account. However, the results provide a valuable order of magnitude benchmark for assessing various scenarios for reducing the embodied environmental effects of future housing designs.

The analysis results were summarised in terms of building totals and on a per square meter of gross floor area basis using six key environmental measures: embodied energy use; weighted raw material use; greenhouse gas emissions (both fuel and process generated); measures of air and water pollution; and solid waste emissions.

The following table outlines the major material differences between the two house designs.

Building Component	1970s Vintage Design	R2000 House Design
Gross Floor Area	207.4 m^2	207.4 m^2
Design (Mort.) Life	30 yrs.	30 yrs.
Primary Structure	Wood light frame construction w/ basement	Wood light frame construction w/ basement
Envelope	2x4 wood studs (GRN), 89 mm fibreglass insulation (R-12)	2x6 wood studs (KD), 140 mm fibreglass insulation (R-20)
Exterior cladding/ fenestration	Brick / wood operable window, standard dble glazed	Brick / PVC operable window, Low "E" argon dble glazed.
Roofing system / insulation	Light frame wood truss, asphalt shingle, 150 mm fg batt (R-20)	Light frame wood truss, asphalt shingle, 375 mm fg batt (R-50)

Figure 2: Material and Design Summary

For both designs, NRCan stipulated a 30-year life span, which equates to the length of the typical mortgage. While somewhat arbitrary, the 30-year life provides an initial reference basis for the study. To take account of recurring embodied effects, the following assumptions were made in discussion with NRCan.

1970s vintage design:

- roofing renewed every 20 years, with a second layer of shingles added to the initial layer at year 20 (the roofing added at year 20 would still have another 10 years of life; to confine the analysis to 30 years, only half of the materials and their consequent embodied environmental effects for re-roofing were attributed to the design);
- ceiling insulation upgraded from 6" (R20) to 8.5" (R28) in year 20 (1990 standard);
- original wood windows replaced at the end of 20 years with PVC windows having both a low "E" coating and argon between the two double panes; and
- by year 30, 12% of the new thermal glazing units assumed to have failed and been replaced (obviously, these failures would not have occurred all at once, but over the 10 year period - for modelling purposes, however, the team selected to model the failures at year 30).

R2000 vintage design

- re-roofing schedule described above;
- at year 20, 25% of the thermal glazing units assumed to have failed and been replaced;
- over the next 10 years (to year 30), 50% of the window units replaced;
- clay brick assumed to last the life of the building (may require re-pointing, but the team omitted re-pointing since it is likely to be of minor significance).

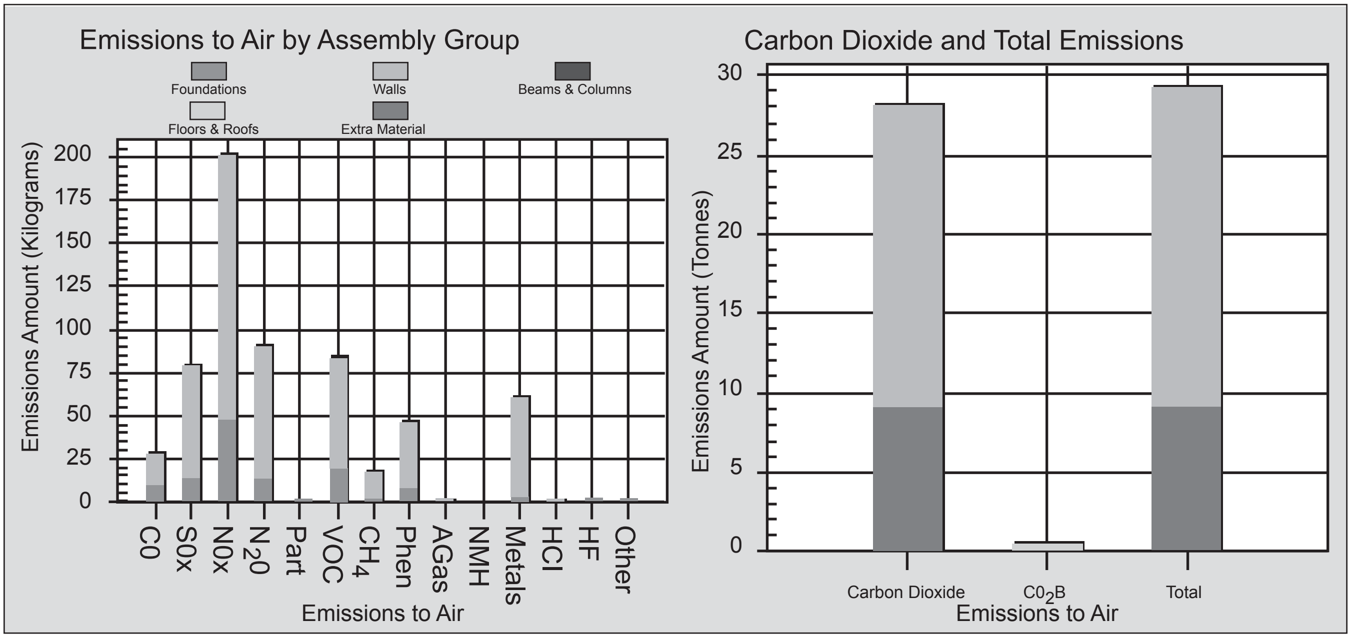

Figure 3: House design 2 - Emissions to Air by Assembly Group

Embodied Effects

1970s Design: Based on this assessment, we estimate that a 1970s vintage house, as built and maintained for 30 years, had the following embodied effects per square meter:

- embodied 2.4 Gj of energy;
- required 0.6 tonnes of raw materials (weighted to take account of resource extraction effects);
- produced greenhouse gases equivalent to 350 kg of CO2; and
- resulted in 30 kg of solid waste.

From an embodied energy perspective, the structural systems and envelope each account for roughly 50% of the building's initial environmental burden. Together, they account for over 90% of the total embodied life cycle burden, with maintenance and replacement accounting for the remaining 10%. Within the initial structure, the below grade component is the single largest contributor to the environmental load for the structure. The use of both concrete and steel (used in the beams, lintels and columns supporting the wood floor) is the primary reason for the below grade component's greater environmental burden. This is equally true for the R2000 design.

By far, the largest contributing component to the overall energy and global warming results of the initial above grade envelope (as distinct from the initial structure) is clay brick, followed by gypsum board and insulation materials.

While contrasting the effects of the structural, envelope materials, maintenance and replacement components is useful, the shear enormity of the total embodied energy involved can easily go unnoticed. To help humanize the results, the Institute made a quick calculation, which revealed that the life cycle energy embodied in the 1970s home design is equivalent to driving a small car (consuming 8L/100km) a total of 191,000 km, almost five times around the earth.

R2000 Design: Relative to the 1970s design, the R2000 design embodies about 15% more energy over its life. Both the structure and envelope are more energy intensive due to increasing the exterior wall stud size to 2"x6" from 2"x4", the use of kiln-dried wall studs (rather than green, unseasoned lumber in the 1970s design) and adding additional insulation to both the walls and roof. However, the maintenance and replacement embodied effects are lower due to not having to upgrade the roof insulation level or completely replace the window units over the 30 year timeline.

Operating Energy

As the table below indicates, annual space heating costs for the R2000 home are only 27% of the costs of heating the 1970s home (a factor of 4 decrease); total R2000 annual operating costs are 42% of 1970s' costs, and total 30 year life cycle energy of the R2000 house is 46% of the 1970s figure. About 50% of the total improvement in operating energy efficiency can be ascribed to better envelope design, with the remainder being a function of improved HVAC equipment.

Component	1970s	R2000
Life cycle embodied energy	487 Gj	568 Gj
Annual space heat/AC	249 Gj	67 Gj
Hot water heating	29 Gj	27 Gj
Lights and appliances	32 Gj	32 Gj
Ventilation and fans	5 Gj	6 Gj
Total Annual Operating energy	315 Gj	132 Gj
Total 30 yr Life Cycle Energy (LCE)	9937 Gj	4528 Gj
Total LCE as % of 1970s design	100%	46%

Figure 4: Total Embodied and Annual Operating Energy: Comparison Summary

Conclusions: 1970s Design versus R2000 Design

In summary, the results of this study show that the relatively small increases in embodied material effects incurred by building a house to R2000 standards in Ottawa are more than offset by significant reductions in related operating energy burdens (space heating/air conditioning) over a building's life.

The following chart provides more detail on the higher embodied effects that result from building to R2000 standards—the environmental price for achieving impressive gains in operating costs. Note that for each of the summary measures, the 1970s design has been set at 100%, and the R2000 results have been normalized to that benchmark.

The R2000 design embodies 20% more energy, emits 25% more air pollutants and 25% more global warming gases. However, when these embodied effects are combined with those of space heating, the R2000 house design ends up using 60% less energy and emitting 61% fewer greenhouse gases over a 30 year time period.

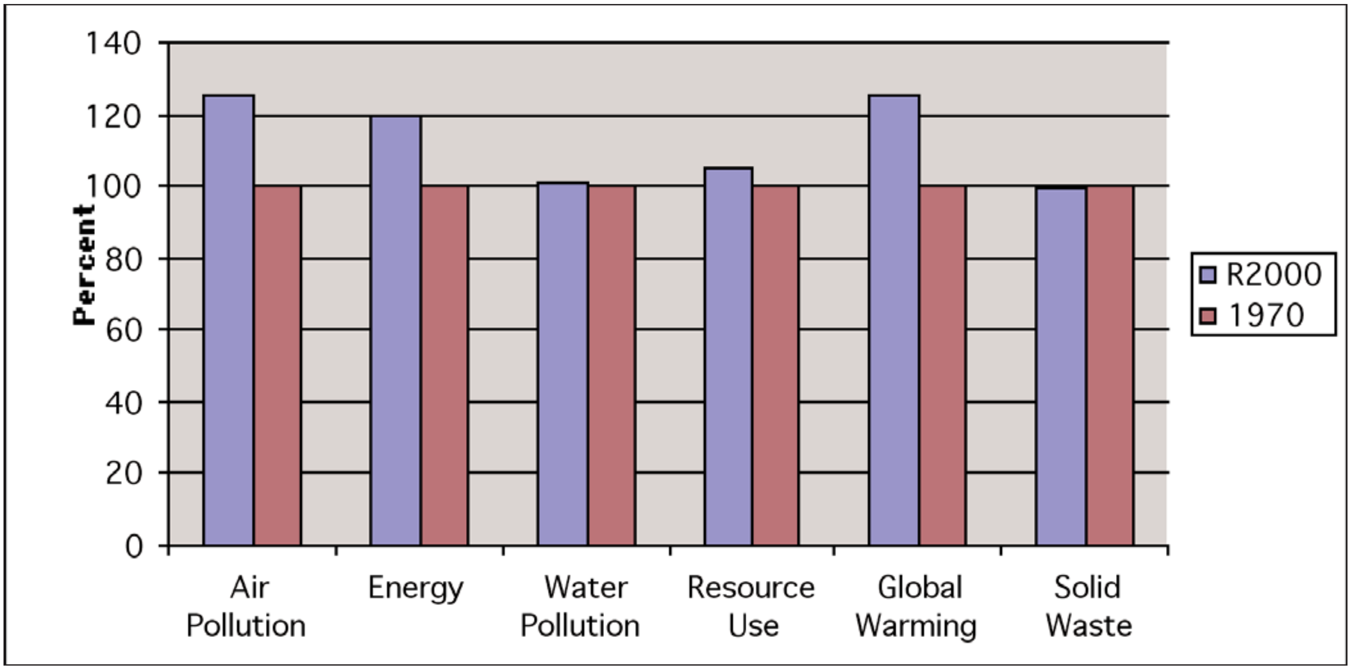

Figure 5: Comparison of R2000 and 1970s House Designs Across Six Environmental Measures (Normalized to 1970 results)

The critical lessons from this and similar case studies, as well as the earlier sections of this article, are to:

- focus on overall environmental performance measures, such as primary energy use, global warming, and toxic releases to air and water;
- consider the performance measures over the entire life cycle of a building, resisting the tendency to take account of embodied or operating effects in isolation;
- take potential environmental effects into account as early as possible in the design process before significant effects are locked in;
- recognize the material interrelationships and ensure that comparisons are made on a functionally equivalent basis;
- maintain a healthy scepticism about 'green' claims, recognizing that most material choices involve trade-offs in terms of the environmental effects generated at different stages in the life cycle; and, above all,
- be wary of simplistic answers to what are inevitably very complex questions and issues.

REFERENCES

1. Howard, N., Paper presented to Green Building Challenge, International Framework Committee meeting, Santiago, Chile, 2001.
2. Cole, R. et. al., *Life Cycle Energy Use in Office Buildings*, Athena Sustainable Materials Institute, 1994.
3. Anderson, J. and Howard, N., *The Green Guide to Housing Specification*, BRE, 2000.
4. Anderson, J. and Shiers, D. E., *The Green Guide to Specification: an Environmental Profiling System for Building Materials and Components*, BRE, 2002.

SELECTED INTERNET INFORMATION SOURCES

http://www.athenaSMI.ca
Athena Sustainable Materials Institute

http://www.bfrl.nist.goc/oae/softare/bees.html
Building for Environmental and Economic Sustainability

http://www.buildinggreen.com
BuildingGreen (Environmental Building News and GreenSpec Directory)

http://www.greenbuildingsbc.com
Green Buildings BC

http://www.iisbe.org
International Initiative for a Sustainable Built Environment

http://www.wbdg.org
Whole Building Design Guide

http://cagbc.ca
Canada Green Building Council

http://www.sbcanada.org
Sustainable Buildings Canada

http://www.usgbc.org
United States Green Building Council

http://www.nrel.gov/hpbportal/metrics
High Performance Building Metrics

http://www.nrel.gov/lci
U.S. Life Cycle Inventory Database Project

QUESTIONS

1. What distinguishes the different levels of tools, and when in the design process might tools from each level be best used?

2. Using the 1970s versus R2000 home case study results, use a calculation to show the relative importance of embodied energy compared to operating energy. Explain the change in this relationship over the past 20 to 30 years.

3. LEED 2.1 includes a credit for the use of rapidly renewable materials. The intent of the credit reads as follows:

   "Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials." (LEED™ 2.1 Intent, MR Credit 6)

   The corresponding requirement to achieve the credit states the following:

   Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year or shorter cycle) for **5%** of the total value of all building materials and products used in the project.

   Name at least four environmental issues or concerns ignored in this credit that would be taken into account in an LCA?

4. Identify three factors that should be taken into account to ensure functional equivalence when comparing steel, wood and insulated concrete form (ICF) structural systems for a new three-story building?

5. List four contributors to recurring embodied effects for an office building with a concrete structure and curtain wall envelope system.

6. There are CO_2 calculators that estimate the CO_2 releases from energy combustion in various kinds of processes (i.e., space conditioning, manufacturing processes, etc.) over a specified time period. Are such calculators likely to provide accurate estimates of the global warming implications for a building design, including embodied effects? If not, why not.

7. List the seven design objectives under which you can search for design guidance on the Whole Building Design Guide web site.

8. You are considering the comparison and selection of floor coverings for an office building and do not have the resources to undertake full LCAs. What life cycle considerations would you take into account to ensure a proper evaluation? Name one tool that you might use to get some LCA insights.