The Environmental Implications of Building New *versus* Renovating an Existing Structure

Wayne Trusty and Jamie Meil
ATHENA™ Sustainable Materials Institute
P.O. Box 189, Merrickville, Ontario, Canada, K0G 1N0

INTRODUCTION

This case study demonstrates the value of using the ATHENA™ life cycle assessment (LCA) tool during the conceptual design process in two ways:

1. to gauge the environmental implications of retaining the structure and envelope of an existing building instead of replacing it with a new structure; and
2. to help weigh building performance goals against design and material mix choices for a new building.

THE CASE STUDY BUILDING AND METHODS

As the basis for the assessment, our analysis drew upon two versions of an office building design prepared for Natural Resources Canada's C2000 Building performance program. The design basics, common to both versions, include a single basement level and 13 above grade floors with a total gross floor area of 21,740m^2. The two versions of the building, which are characterized in terms of operating energy performance as the ASHRAE 90.1 and C2000[1] versions, differ in their respective fenestration type and area, overall insulation level, and HVAC system efficiency.

Table 1 below outlines both the common and different elements incorporated in the ASHRAE and C2000 designs as well as the operating energy use estimates.

Table 1 — Design/Energy Use Summary: ASHRAE & C2000 Office Building Versions

Building Parameter		ASHRAE 90.1 Design	C2000 Design
Structure		Concrete drop panel system	same
Envelope	Exterior cladding	40%Brick/60% curtain wall combination	same
	fenestration	22%, double pane, low "E"	37%, triple pane, Low "E"
	Insulation level	Approx. R 22	Approx. R27
DOE2 Operating Energy Est.*			
	HVAC	102.6 kWh	39.7 kWh
	Lighting, plug load, etc.	77.4 kWh	42.3 kWh
	Total Operating Energy	180 kWh	82 kWh

Note: * DOE 2 simulation results were provided in the original C2000 program report.

The scope of the environmental LCA undertaken using ATHENA™ was limited to the office building's initial structure, envelope components and related annual operating energy. This limited focus was necessary due to the objectives of the study itself, which did not require study of common elements in the comparative scenarios. The results therefore underestimate the total life cycle environmental impacts of constructing a new building.

ATHENA™, the Institute's environmental life cycle assessment decision support tool, has been under development since the early 90s. 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. The model summarizes results across six key environmental measures covering initial (embodied) energy use; weighted raw resource use; greenhouse gas emissions (both fuel and process generated); measures of air and water pollution; and, solid waste emissions.

---

[1] The objective of the C2000 Program is to promote the adoption of leading-edge technologies and building management techniques to attain a very high performance – a 50% improvement in operating energy over the ASHRAE 90.1 standard

RESULTS

Initial New Building Impact (ASHRAE & C2000 Performance Designs)

Tables 2 below summarize the office building environmental life cycle assessment results for the two performance designs by component grouping on both an absolute and per unit of floor area basis. The first year operating (HVAC) energy effects per m^2 are also reported.

Table 2 – Summary: Initial Environmental Impact Profile by Performance Design

Design by Assembly Components	Embodied Energy Gj		Global Warming Potential Eq. CO_2 tonnes		Weighted Resource Use tonnes		Solid Waste tonnes	
	Ashrae	C2000	Ashrae	C2000	Ashrae	C2000	Ashrae	C2000
Structure	25414	25414	6829	6829	25674	25674	1140	1140
Envelope	7873	9032	1132	1369	1501	1623	163	176
Total	33246	34446	7961	8198	26875	26997	1303	1316
Per m^2	1.53	1.58	0.37	0.38	1.23	1.24	0.06	0.06
HVAC Energy (per m^2 per year)	0.39	0.15	0.14	0.03	0.05	0.06	<0.01	<0.01

Note: Global warming and other effects of HVAC operating energy reflect the upstream production and transportation of energy as well as its combustion. Air and water pollution effects, while calculated, are not reported here to save space

Both the ASHRAE and C2000 performance designs share the same structure, which accounts for roughly 75% of the building's initial embodied energy burden. But the C2000 version incorporates about 15% more embodied energy in its envelope materials compared to the ASHRAE design. Overall, then, there is only a 4% difference between the two designs in terms of embodied energy for their respective structure plus envelope materials. For the C2000 design, the modest increase in material use contributes, in combination with increased HVAC efficiencies, to a 2.5 fold improvement in annual operating energy use.

It's notable that as operating energy efficiency improves, the importance of the initial structure and envelope embodied energy increases. In the less efficient ASHRAE design, initial embodied energy is equivalent to about 4 years of HVAC operating energy use, but in the C2000 design, initial embodied energy is equivalent to approximately 10 years of operating energy. The relative importance of embodied energy would be even greater if the estimates covered all of the recurring as well as excluded building elements.

While contrasting the embodied energy of the structural and envelope materials with operating energy is useful, the shear enormity of the total energy involved can easily go unnoticed. To help humanize the results we made a quick calculation which revealed that the energy embodied in the structure and envelope of the ASHRAE design is equal to driving a small car (consuming 8L/100km) a total of 12 million km or 300 times around the earth.

In summary, just building a new square meter of ASHRAE performance level office floor space –
a) requires 1.53 Gj of energy and 1.23 ecologically weighted tonnes of raw resources;
b) produces greenhouse gases equivalent to 370 kg of $CO2$;
c) requires 19.7 cubic metres of air and 2 cubic metres of water to dilute these pollutants to acceptable levels; and,
d) results in 60 kg of solid waste going to landfill.

This conservative assessment clearly demonstrates the significant environmental impacts related to materials comprising a new building, impacts that become relatively more significant as steps are taken to improve a building's operating energy.

Environmental Impact Avoidance Associated with Renovating

When choosing to renovate, a building's structure is typically retained but the original envelope may or may not be left intact. So environmental impact avoidance scenarios for a major retrofit/renovation involve contrasting a complete demolition and new construction activity with:

a) retention of the structural system only and estimation of the environmental impacts avoided by not demolishing the structure (minimum avoided impact case); and
b) estimation of the impacts avoided by not demolishing either the structural system or the envelope (maximum avoided impact case).

Minimum Avoided Impact Case
The minimum avoided environmental impact case involves saving only the structural system of an existing building, with reconstruction of the rest of the building. The avoided impacts equal the effects of:

demolishing a structural system + rebuilding a comparable structural system.

Here the effects of demolishing the envelope are not avoided and we assume that the environmental cost of rebuilding the envelope on an old building would be the same as constructing the envelope on a new building.

Maximum Avoided Impact Case
This case involves saving the envelope as well as the structure and avoided impacts equal the effects of:

demolishing a structural/envelope system + rebuilding a comparable structural/envelope system.

Table 3 summarizes the energy savings and other avoided environmental impacts for the *maximum* avoided impact case. The results for the minimum avoided impact case, in which only the structural system is retained, can be readily derived from the estimates in Table 3 by simply subtracting the values for constructing the envelope in each impact category.

Table 3 – Results Summary: Environmental Impact Avoidance Scenario

Design by Assembly Components	Embodied Energy Gj	Global Warming Potential Eq. CO_2 tonnes	Weighted Resource Use tonnes	Solid Wastes tonnes
Structure Construction				
Below grade	2183	636	2746	
Above grade	23231	6193	22628	94
Sub-Total	25414	6829	25674	1046
Envelope Construction				
	7873	1132	1501	1140
New Construction Totals				
	33246	7961	26875	163
Per m^2	1.53	0.37	1.23	1303
Demolition Energy[1.]	3073	1848	304	0.06
Total Avoided Impacts				
	36319	9809	27179	831
Per m^2	1.67	0.45	1.25	2134

Note 1: Demolition of cast-in-place structure only; no demolition effects available for envelope materials.

The above table does not consider the eventual operating efficiencies of the new versus renovated buildings, another factor that may have a bearing on the decision to build or renovate. Unfortunately, however, the data is not available to adequately include this aspect.

To put the Table 3 results in perspective, we can compare them to the results for construction and operation of a new C2000 building presented in Table 2. By reusing the structure and envelope of a building and thereby avoiding demolition of these component systems, the total energy saved approaches the energy used to construct the C2000 office building and operate it for a year. Alternatively, the total environmental avoidance is equivalent to 10 years of HVAC operating energy for the C2000 office building design. Either perspective indicates that the avoided environmental impact is indeed, significant.