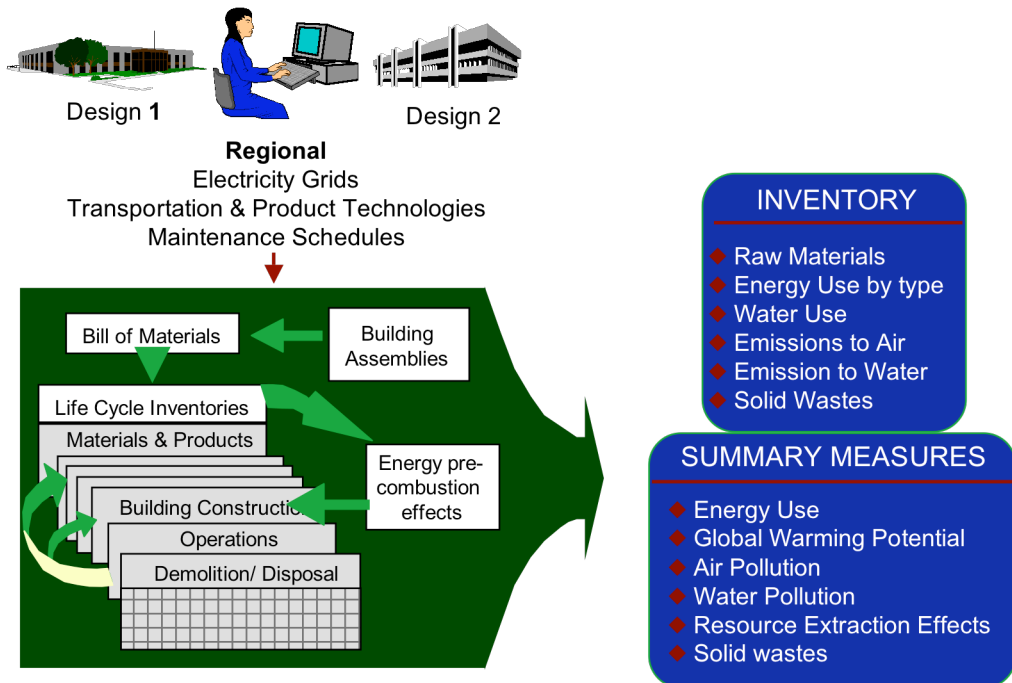


Athena Impact Estimator for Buildings V 3.0.3 Software and Database Overview



1.0 Introduction

The goal of this document is to present an overview of the ATHENA® Impact Estimator software and relational databases by providing an indication of the inner workings of the tool – what it does and how it does it – and the various databases it contains.

The Impact Estimator is a whole building, environmental life cycle based decision support tool for use by building designers, product specifiers and policy analysts at the conceptual design stage of a project. The tool focuses on the conceptual stage, as this is when key decisions are first made about the shape and material make-up of a building's structure and envelope. It takes comprehensive life cycle inventory information and makes it easily accessible to the building community so they can make more holistic and informed environmental decisions.

The report starts with a high level description of the tool's use and capabilities. It illustrates the relationships between building materials, components and assemblies, how they were arrived at, and how they are called upon in the software. It also outlines the various life cycle stages the software supports and the methods used to derive a complete building environmental life cycle inventory and impact assessment profile. The software's embedded databases are also explained, highlighting their use within the tool.

Throughout this document various database and model workings are described by way of example to provide the reader a more illustrative understanding of the tool's inner workings. However, this document is not intended as a user's guide and it does not attempt to explain step-by-step procedures.

The software itself has undergone various incarnations. It first started as a spreadsheet model and was then migrated to a C++ object oriented software design platform. It has now been completely re-written in visual basic. From time to time, this report touches upon new features and capabilities that have been added to the new version.

2.0 High Level Description

The Impact Estimator software is a decision support tool, not a scoring or rating system. The software indicates the environmental implications of different material mixes or design choices and the user can then consider the trade-offs among the various environmental effects. In fact, the essence of the software's decision support role is its ability to compare up to five design scenarios across a set of selected summary measures. When using the software, a user may have two or more building designs already in mind or they may start with a baseline design and then look at various ways of improving that design.

The model provides a cradle-to-grave Life Cycle Inventory (LCI) profile for a whole building over its expected life. The inventory results comprise a long list of highly speciated flows from and to nature in the form of energy and raw material flows as well as emissions to air, water and land. The following current set of impact measures is based on the inventory results:

- Primary energy use;
- Solid waste;
- Global warming potential;
- Air and water pollution indexes; and
- A valuation or weighted measure for resource extraction effects, where the weights reflect survey results on the relative environmental effects of extracting different resources.

Version 4 will support the following measures using the EPA TRACI formulations where relevant:

- Global Warming Potential -CO₂ equivalent mass
- Acidification (Air) Potential - moles of H⁺ ions equivalent mass
- Human Health Air -Mobile Potential -PM_{2.5} equivalent mass
- Eutrophication (water) Potential - N equivalent mass
- Smog (air) Potential - NO_x equivalent mass
- Ozone Depletion (air) – CFC 11 equivalent
- Total Fossil Energy GJ

The absolute value table will also include Total Energy and Total Renewable Energy as separate line items. The Weighted Resource Use measure will be retained pending the development of an internationally recognized measure of land use effects related to resource extraction.

As the user inputs information, a component bill of materials is determined, at which point the software applies the Institute's LCI databases for product extraction and manufacturing, transportation, on-site construction and ongoing maintenance and replacement. It also takes into account structural system demolition and transport to landfill of those materials that are currently landfilled. However, it does not yet contain data regarding what happens over time in the landfill.

3.0 Software Workings

3.1 Overview

Depending upon user-supplied information, the software is able to perform a variety of calculations. For instance, when the project's location is selected from a list of supported regions, the software turns on appropriate electricity grids, transportation modes and distances and even product manufacturing technologies applicable to the product mix for the selected region. The choice of expected service life, type of building and where relevant, whether the building is owner occupied or rental, turns on effects specific to the maintenance, repair and replacement for envelope materials such as roofing, cladding and window systems.

The IE also allows the user the option to input the building's annual operating energy by fuel type. It is then able to calculate primary operating energy, including pre-combustion energy (the energy used to extract, refine and deliver energy) and the related emissions to air, water and land over the life cycle of the building. The software can subsequently compare and contrast the life cycle operating and embodied energy and other environmental effects of the building design, thus allowing the user to better understand the inherent trade-offs associated with adding more envelope materials (eg., insulation) with reductions in operating energy use.

The user defines the building assemblies for a project in terms of their geometry and material make-up or composition from both a structural and envelope perspective. The software is capable of modeling well over 1000 structural and envelope assembly combinations and is generally applicable to more than 90% of the typical North American building stock.

3.2 Assembly and Material Considerations

An assembly is made up of basic materials such as concrete, wide flange steel beam, or softwood lumber. Some basic materials may be combined off-site into a component (e.g., wood or steel roof truss, pre-cast concrete double T beam) before arriving at the building site. The software has detailed LCI information for individual basic materials as well as for components. It also contains estimates of on-site construction effects.

Assemblies are currently disaggregated into groups and types — foundations, walls, floors and roofs, and columns and beams. A set of assembly types is represented within each assembly grouping (e.g., steel HHS columns with steel wide flange beams).

As mentioned, the software is capable of modeling well over 1,000 structural and envelope assembly combinations. Below is a list of basic structural assemblies supported by the model, each of which can have many combinations depending on information entered in the input dialogue boxes (see *Figure 1 example*).

Foundations

Concrete footings – perimeter or column

Concrete slab on grade.

Walls (Exterior load bearing and Interior non-load bearing):

Wood stud walls with or without plywood or OSB sheathing

Steel stud walls with or without plywood or OSB sheathing

Concrete block

Concrete cast-in-place

Curtain wall

Concrete tilt-up

Insulated concrete form

Beams and Columns

Concrete beam and column

Glulam beam and wood column

LVL beam and wood column

PSL beam and wood column

Wide flange beam and hollow structural steel column

Wide flange beam and hollow structural steel column (Gerber)

Mixed column and beam – mixed material system (e.g., LVL beam on concrete column)

Floors and Roofs

Concrete flat plate on column

Concrete flat plate on drop panel column (parking garage)

Concrete hollow core

Concrete pre-cast double "T"

Open web steel joist, "Q" deck

Steel joists with structural wood sheathing (decking)

Glulam joists and solid wood decking

Wood "I" joists with structural wood sheathing (decking)

Light frame wood trusses (parallel or pitched) with structural wood sheathing (decking)

Wood trusses with steel web and structural wood sheathing (decking)

Solid wood joists with structural wood sheathing (decking)

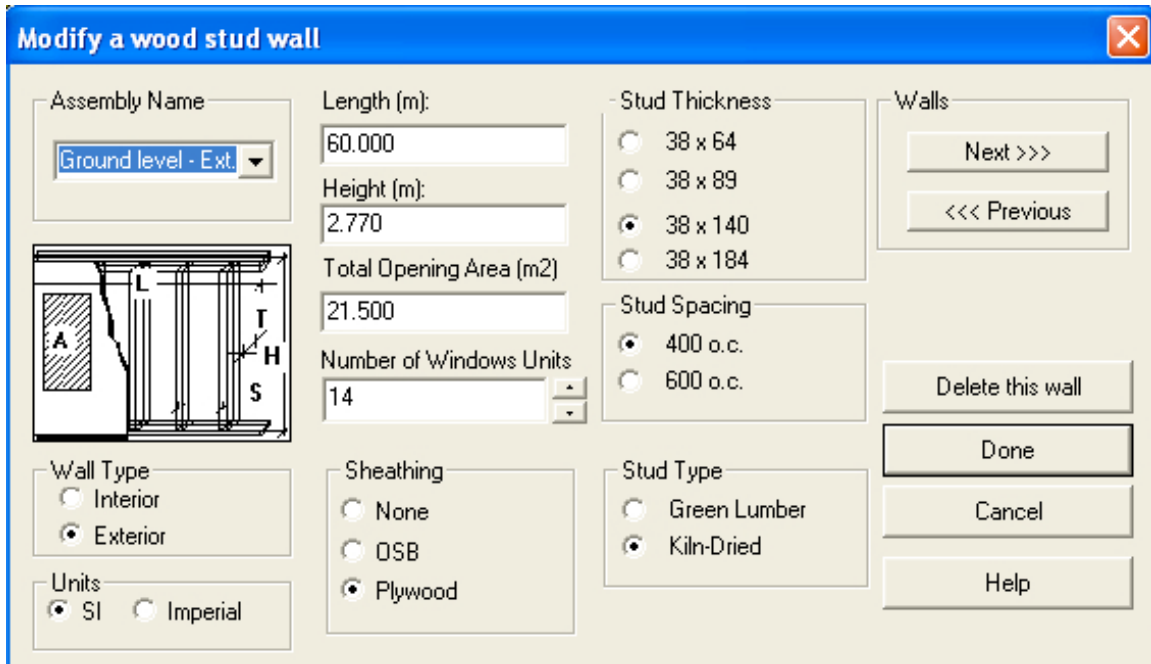


Figure 1

Non-structural, envelope materials are based primarily on the surface area of the specific assembly to which they are to be applied. For example, both insulation and gypsum board materials are added to an assembly on the basis of type and thickness and the EI determines the amount based on the area of the assembly. Windows, on the other hand, are determined based on the total area of openings as well as the number of openings indicated by the user for the assembly (*Figure 1*). All of these openings are assumed to be windows in the case of exterior walls, and doors in the case of interior walls. For windows, the software determines the total frame perimeter for the window (either as a fixed or operating frame), and the hardware and net glazing required for the type of window selected. Data has not yet been developed for doors, but there is a placeholder for later addition of these data.

3.3 Bill of Materials

When the user selects an assembly the software determines the associated bill of materials. As more assemblies are selected, the software aggregates the bill of materials to the whole building level. For example, a user enters a “slab-on-grade” assembly by specifying its geometry (length, width and thickness) and its attributes – e.g., concrete strength class, fly ash use and steel reinforcement from a pick list of supported options. (*Figure 2*)

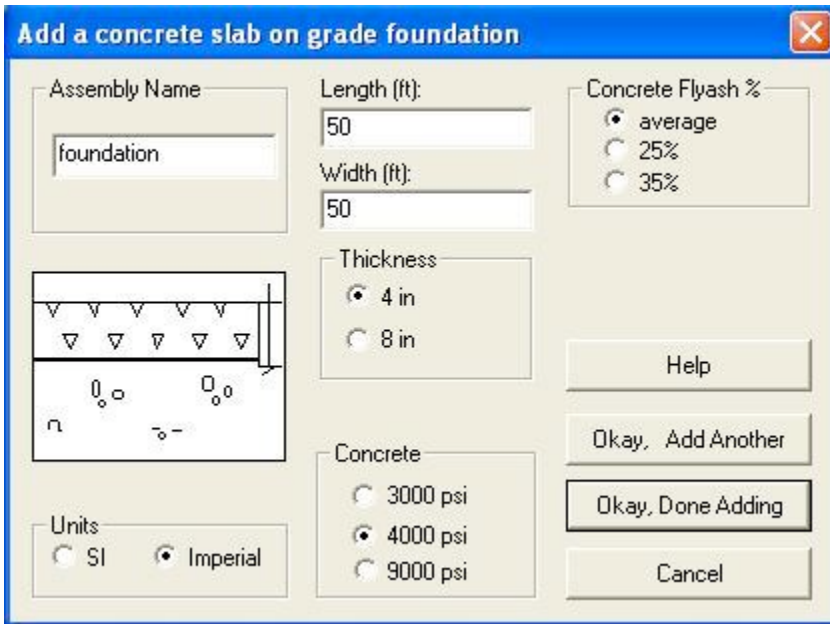


Figure 2

The model then calculates the amount of concrete and the mass of steel reinforcement and adds them to the “bill of materials”. (Figure 3)

	Quantity
Concrete 30 MPa (flyash av): yd3	31.8942
Welded Wire Mesh / Ladder Wire: Tons	0.2313

Figure 3

The user defines envelope material layers applicable to the assembly (e.g., below-grade vapor barrier and insulation by type and thickness as in Figure 4).

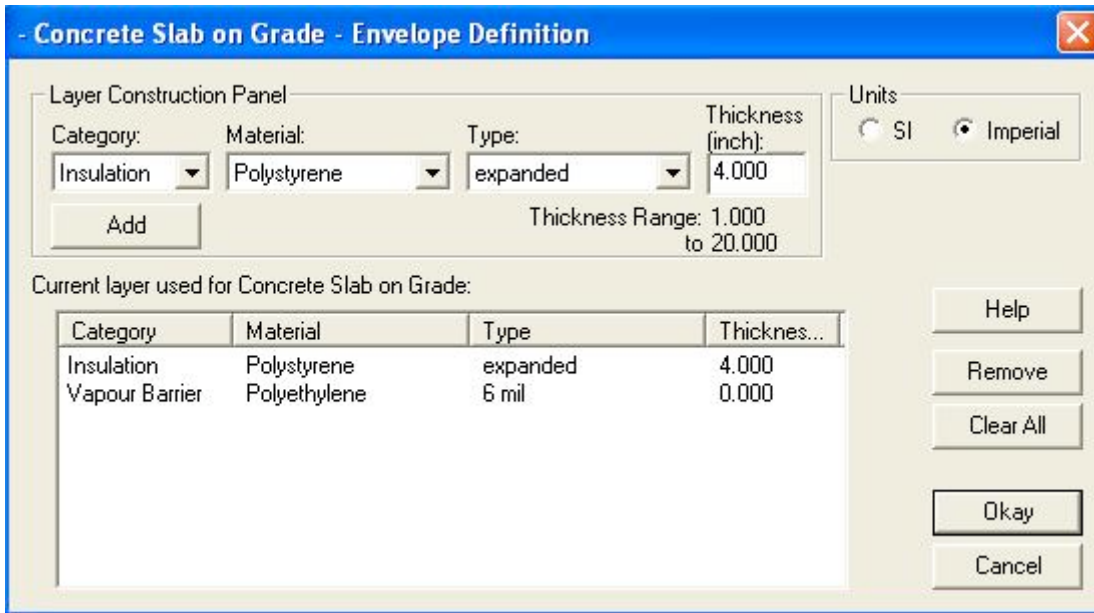


Figure 4

The model then estimates the quantities of these “envelope” or non-structural materials using the previously defined assembly geometry and adds these materials to the bill of materials (*Figure 5*). We refer to this type of bill of material calculation as a “prescriptive” quantity take-off – the user prescribes a set of elements comprising the assembly instead of the model completing any “engineered” quantity take-off calculations.

	Quantity
Concrete 30 MPa (flyash av): yd3	31.8942
Nails: Tons	0.0158
Welded Wire Mesh / Ladder Wire: Tons	0.2313
Expanded Polystyrene: sf (1")	10370.7408
6 mil Polyethylene: sf	2651.7633

Figure 5

We refer to a second kind of quantity take-off or bill of materials determination as a “deterministic” method. An example of this method would apply to intermediate floors, roofs, and column and beam systems. In these cases the user specifies

supported spans, bay sizes and live loads and the model determines the depth or size of a building element (structural floor element, supported slab, beam and column, etc.) to satisfy the selected assembly design parameters. (Figure 6)

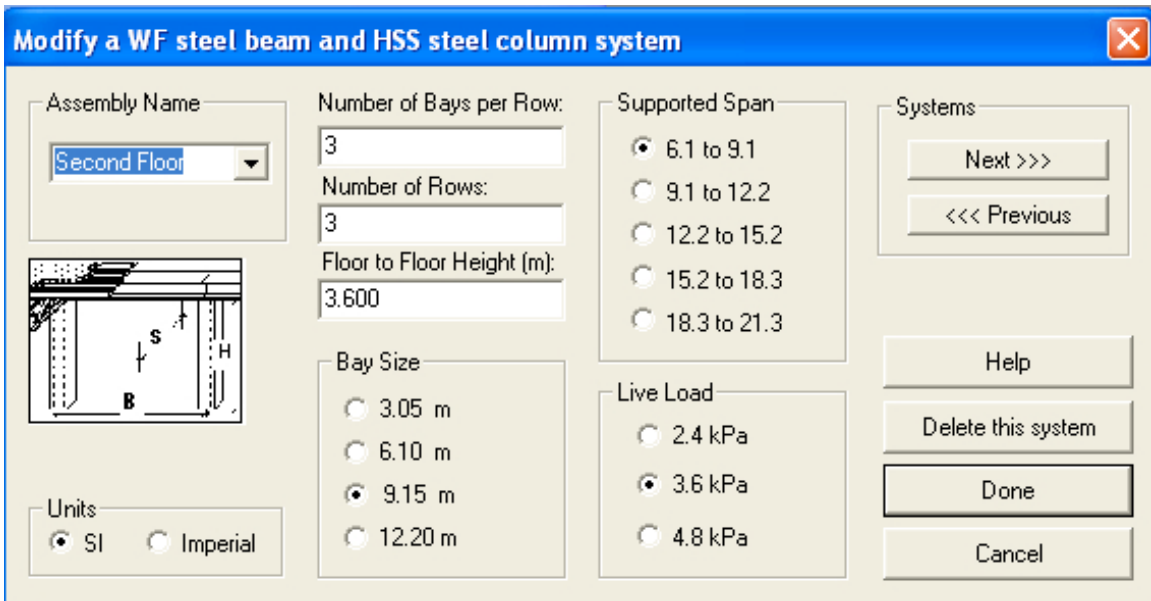


Figure 6

The graphic below (Figure 7) shows the basic material sizing calculation information (lbs per foot) used for a steel wide flange beam for a given bay size.

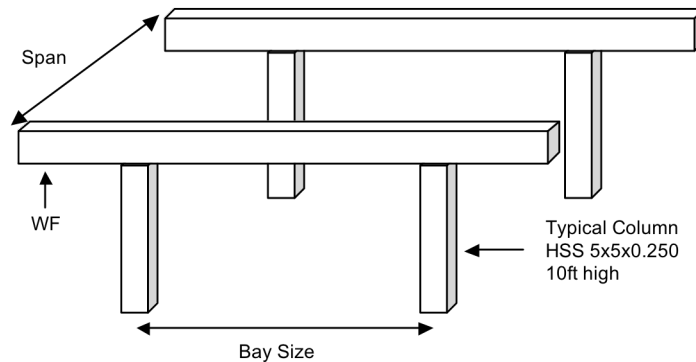


Figure 7

Figure 8 below shows the quantity take-off curves used to determine the weight of steel beam required based on the bay size and span for a 50 psf live load. For the purpose of developing algorithms in the EI, curves of this type have been segmented into linear sections. The software then uses the beam sizing for the high end of the linear segment corresponding to the specified bay size and span. Similar curves are used for the different user-selectable live loads.

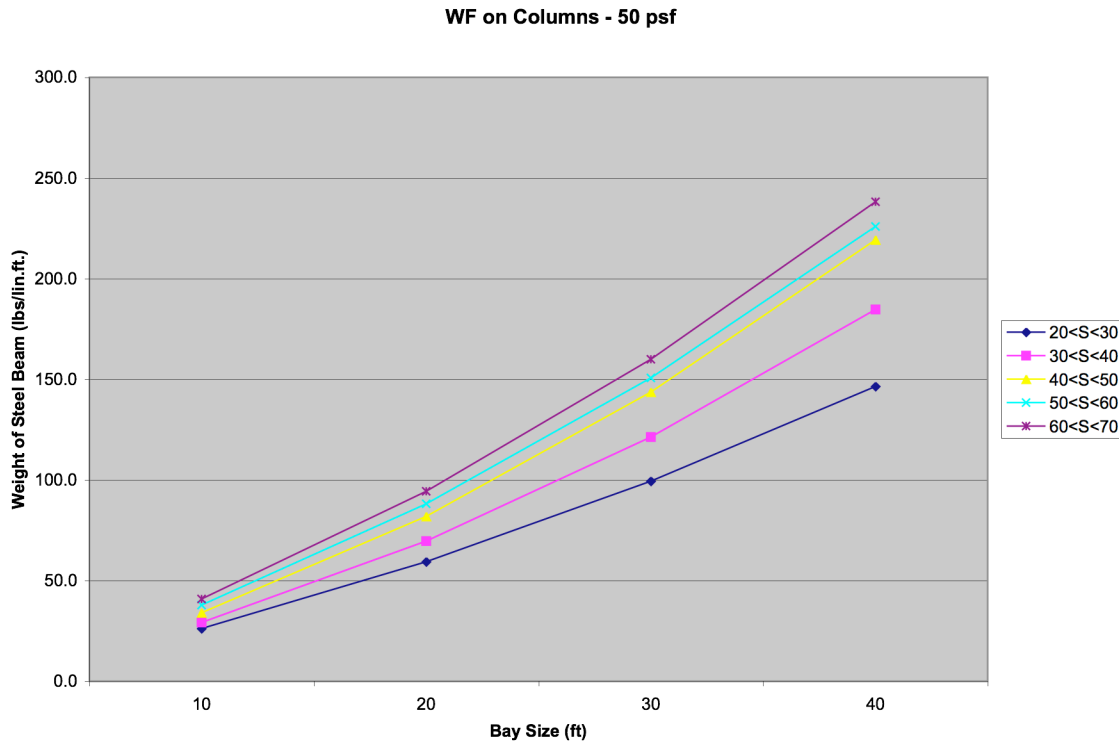


Figure 8

The IE software is not a design tool; it is intended to express a design in sufficient detail for the purpose of estimating the environmental effects of a building. As indicated previously, that estimate starts with the bill of materials. These bill of material quantity take-offs have been compared against detailed manual take-offs and have been found to be within +/- 10% of typical “engineered” quantities. Taking other factors into account (e.g., assumptions and uncertainties in the basic LCI data, many of which are compensating in terms of ultimate impacts), the Institute considers any comparative impact measure differences of 15% or less as being equal or insignificant.

The software assumes a building will be built on the site and does not take account of site development issues such as land disturbance, eco-system alteration and destruction of vegetation. Such effects are very site specific and the intent of the software is to focus on the building design issues as opposed to these site-specific issues.

3.4 Regional Considerations

In the software, cities are used to designate regions because material or product flows, energy use and other considerations are not readily defined by strict political boundaries. The user selects the city that best represents the location of the building site.

The IE was initially developed for Canada and includes regions designated by the cities of Halifax, Quebec City, Montreal, Ottawa, Toronto, Winnipeg, Calgary and Vancouver. Since its original commercial release in 2002, a US average was

added to the software and more specific US regions were added over time. Currently, Pittsburgh, Minneapolis, Atlanta and Orlando are included. In the new version, US regional coverage will be expanded to include Seattle, Los Angeles and New York, with additional regions to follow in due course.

For each region, a regional product market share analysis is completed to determine where products are typically coming from. This information is used to develop weighted average life cycle inventory profiles for the products, as well as weighted average transportation profiles based on distance and modal split. Some products, such as cement and aggregate, are more regional while others, such as aluminum, travel greater distances, and some products are often sourced offshore (e.g., steel). For modeling purposes, to the extent possible and where relevant, all offshore products are treated as though they were manufactured in North America, an assumption that may change in the future as more reliable and consistent international datasets become available.

Electricity supply is also an important consideration and the software supports regional locations in various ways. First, it considers whether a region has a defined electricity grid or whether it is part of a larger interconnected grid. For instance, a location such as Montreal is in the Quebec electricity grid and Quebec is a net exporter of electricity to the Eastern North American grid. We therefore use the Quebec grid for electricity use in that region. For other regional locations the electricity may come from a larger regional grid, in which case the IE uses data for that grid. For example, the region represented by Atlanta is the Southeast Electric Reliability Grid (SERC) and the model uses that grid to represent the electricity use in the region.

This approach to electrical grids is taken when calculating electricity-related environmental burdens associated with the manufacturing of basic materials, products and components used in a building, as well as electricity used in the construction and maintenance of a building, including annual operating energy. As an example, when construction grade plywood is specified for use in Ontario, the model locates the closest supplier (British Columbia) and applies the BC electricity grid in the manufacture of plywood, but uses the Ontario electricity grid to calculate any on-site electricity use in construction of the plywood based assembly. In the next version of the IE, and due to new power wheeling agreements across North America, the Institute plans to adopt the three major interconnection grids- Eastern, Western and Texas- as the basis for electricity usage in the model. However, provinces and states that are deemed net exporters of electricity to the grid will remain as standalone grids in the model.

3.5 Database Details

The following table sets out both structural and envelope materials supported by the model and the vintage of these databases.

Product	Vintage	Comments
Concrete products		
Ready Mix Concrete (3000, 4000, 9000 psi with various high volume fly ash levels (average, 25% & 35%) specified on a volume basis	CDN 2005 US 2004	<ul style="list-style-type: none"> Canadian regional cement data updated from original 1993 data (concrete designs remain unchanged) US data reflects PCA design mixes and average cement for the US Institute report available. US cement profile available at US LCI database (www.nrel.gov/lci)
Concrete Masonry Units (CMU) specified on a number of units basis	CDN 2005 US 2004	
Mortar - specified on a volume basis	CDN 2005 US 2004	
Steel Products -specified on a mass basis	CDN 2002 US 2002	<ul style="list-style-type: none"> All product profiles reviewed and adjusted to reflect fuel use by type and mix of EAF and integrated steel production technologies per product in both Canada and the US Institute report available. Integrated profile for US resides in US LCI database (www.nrel.gov/lci)
Nails		
Welded wire mesh		
Screws, nut bolts		
Wide Flange sections		
Open- web joists		
Reinforcing bar		
Hollow structural steel		
Steel tubing		
Hot rolled sheet		
Cold rolled sheet		
Galvanized sheet		
Galvanized decking		
Galvanized studs		
Wood Products – specified on a volume basis	CDN –various US-various	
Softwood lumber (green & kiln dried)		<ul style="list-style-type: none"> Canadian regional data updated in 2000 Corrim data for US reflects PNW and SE production 2004. Institute report available for Canadian cradle-to-gate profile. See Corrim.org or US LCI database (www.nrel.gov/lci) for US data (2005)
Plywood		<ul style="list-style-type: none"> Canadian regional (BC only) data originally developed in 1993. Resource harvesting profile updated in 2000 and complete product profile will be updated in 2008. Institute report available for Canadian cradle-to-gate profile. Corrim data for US reflects PNW and SE production in 2004. See Corrim.org or US LCI database (www.nrel.gov/lci) for US data
Oriented Strand board		<ul style="list-style-type: none"> Canadian regional data originally developed in 1993. Resource harvesting profile updated in 2000 and complete product profile will be updated in 2008. Institute report available for Canadian cradle-to-gate profile.. Corrim data for US reflects PNW and SE production in 2004. See Corrim.org or US LCI database (www.nrel.gov/lci) for US data
Laminated Veneer Lumber		<ul style="list-style-type: none"> Canadian regional data originally developed in 1993 for both LVL and PSL. Resource harvesting profile updated in 2000.

		<ul style="list-style-type: none"> • Institute report available for Canadian cradle-to-gate profile. • Corrim data for US reflects PNW and SE production in 2004. • See Corrim.org or US LCI database (www.nrel.gov/lci) for US data (2005)
Glulam Beams		<ul style="list-style-type: none"> • Canadian regional data originally developed in 1993. • Resource harvesting profile updated in 2000. • Institute report available for Canadian cradle-to-gate profile. • Corrim data for US reflects PNW and SE production in 2004. • See Corrim.org or US LCI database (www.nrel.gov/lci) for US data
Wood bevel siding – 3 species	CDN -various US -various	<ul style="list-style-type: none"> • Canadian regional data originally developed in 2000. • Institute report available for Canadian cradle-to-gate profile. • US profiles based on PNW/SE lumber with Canadian transformation processes (2004) – no report available
Wood tongue and groove siding - 3 species		
Wood shiplap siding - 3 species		
Sheet steel cladding residential		<ul style="list-style-type: none"> • Canadian and US regional data originally developed in 2000. • Institute report available for Canadian cradle-to-gate profile. • Base steel sheet values updated in 2005.
Sheet steel cladding commercial		
Common clay brick (modular and standard)		<ul style="list-style-type: none"> • Canadian clay brick data developed in 1998. Adjusted for US by substituting electricity grids and transportation distances. • Institute report available. • N.A. update planned for 2009
Concrete brick and split faced block		<ul style="list-style-type: none"> • Canadian concrete brick data developed in 1998. • Split faced block updated in 2005. • Adjusted for US by substituting US cement profile, electricity grids and transportation distances. • Institute report available.
Stucco – over porous surface and metal mesh		<ul style="list-style-type: none"> • Canadian data developed in 2001. • Cement portion updated in 2005. • Adjusted for US by incorporating US cement profile and substituting electricity grids, base fuel use and transportation distances. • Institute report available.
PVC vinyl siding		<ul style="list-style-type: none"> • Originally developed in 1998 and updated in 1999. • PVC polymer portion to reflect new 2007 ACC data • See US LCI database (www.nrel.gov/lci) for data
Insulation and barrier products	Various for NA	
Polyethylene vapour barrier		<ul style="list-style-type: none"> • Originally developed in 1998 and updated in 1999. • LDPE polymer portion to reflect new 2007 ACC data • See US LCI database (www.nrel.gov/lci) for data

Air barrier		<ul style="list-style-type: none"> To be added in 2007 based on polypropylene profiles
Mineral Wool		<ul style="list-style-type: none"> Originally developed in 1998 and updated in 1999. Styrene polymer portion to reflect new 2007 ACC data See US LCI database (www.nrel.gov/lci)
Fiberglass		
Polystyrene XPS and EPS		
Polyisocyanurate		
Cellulose		
Polyisocyanurate		
Paint Products	Various for N. America	
Basic latex, solvent based and varnish		<ul style="list-style-type: none"> Originally developed in 1998 and updated in 1999. Institute report available
Gypsum Board Products	Various for N. America	
Regular		<ul style="list-style-type: none"> Originally developed in 1997. Update and expansion planned for 2009. Institute report available
Fire rated		
Moisture resistant		
Gypsum fiber board		
Joint compound and paper tape		
Roofing Products	Various for N. America	
3 tab shingles - organic		<ul style="list-style-type: none"> Originally developed in 2000 and 2001. Institute report available
3 tab shingles - glass		
#15 and #30 organ felt		
Type III and IV glass felt		
Mineral roll roofing		
Clay tile		<ul style="list-style-type: none"> Originally developed in 1998. Adjusted and updated for US by substituting US cement profile, electricity grids and transportation distances. Institute report available
Concrete tile		
BUR organ felt based		<ul style="list-style-type: none"> Originally developed in 2001. Adjusted and updated for US electricity grids and transportation distances. Institute reports available
BUR glass felt based		
Roofing asphalt		
PVC Membrane		
EPDM membrane		
Modified Bitumen		
Windows	Various for N. America	
Wood frame		<ul style="list-style-type: none"> Originally developed in 1998 and updated in 1999. PVC polymer portion to reflect new 2007 ACC data See US LCI database (www.nrel.gov/lci) for data. Adding fiberglass frame in 2008
PVC and PVC clad wood frame		
Aluminum Frame		
Double pane glazing, Low E coating, Argon filled		

3.6 On-site Construction Effects

The onsite construction effects take account of the energy used to transport materials or components from the manufacturer to a notional distribution centre and from the distribution centre to the building site. The transportation distances are based on regional surveys. It also takes account of the energy used to construct the building and the emissions to air, water and land associated with the on-site construction activity. Below, we use the example of applying stucco to a wall assembly to illustrate the calculation of on-site construction effects.

Traditional stucco typically consists of two base layers of cementitious mortar and a thinner finish or topcoat. The base coats are reinforced with wire mesh or extruded metal mesh that is fastened to the studs or wall system with nails or screws. The topcoat finish is typically a cementitious-based mortar, but can also be an embedded stone.

Stucco is normally installed on mid and low-rise building and the installation is typically performed from grade or scaffolding with no energy use due to cranes.

Stucco can be mixed in bins powered by hand or gas engines. Engine powered mixers are more common in larger projects, while hand powered mixers are often utilized in very small or repair projects. Mixers are typically left running for most of the workday (although they are shut down at lunch and break periods). A typical waste factor for stucco is 10%; i.e., 10 % of all materials will be wasted on the job-site – material falling to the ground and over mix that is disposed of in landfill.

In small projects, the cement and sand may be delivered to locations in bags by truck. However, for most projects the materials are delivered and mixed on site by masons. The software utilizes average transportation distances by truck for cement and 60 km by truck for sand.

3.7 Maintenance, Repair and Replacement Effects

Maintenance and repair effects of building materials exposed to the elements or to wear (eg., interior gypsum board) include the following;

- Material usage including quantity take-offs on a square meter basis for maintenance and repair products and components;
- Typical frequency of maintenance and repairs for each of the urban centers given in the software;
- Energy use for maintenance and repair activities;
- Typical transportation mode and distance by region from the distributor to the site for the relative components; and
- On-site waste of maintenance and repair components and their disposition.

Replacement effects of building materials include the following:

- Typical life expectancy (service life) of each material by region, based on empirical evidence; and
- Mass of waste material and its disposition.

Maintenance, repair and replacement schedules have been separately assessed for each of the building types specified in the Impact Estimator. Essentially, the maintenance and repair algorithms in the software assume two levels of maintenance; a more aggressive maintenance and replacement schedule for owner-occupied buildings and a less aggressive schedule for rental and leased properties, with single family residential, institutional, commercial and industrial buildings assumed to be owner-occupied.

The software assumes that replacement materials or components will be the same as those used in original construction. This is almost certain not to be the case, but the alternative is technological forecasting, which would introduce a high level of uncertainty.

In situations where the service life of a replacement material or component exceeds the remaining assumed service life of the building, the difference is credited. For example, a 20-year service life window installed 10 years prior to the end of the building service life will be credited with half of the window's environmental burdens.

Using the stucco example we can further illustrate some of the environmental impacts arising from its repair or replacement. The table below demonstrates a typical stucco repair and its environmental impact for two different regions.

Stucco is rarely replaced in its entirety, although it is commonly over-clad with a different material (such as PVC or wood). For the purpose of the software, we have developed an average frequency of exterior wall cladding replacement for each urban centre supported by the software, under the assumption that the stucco is removed and replaced. See Figure 9 below.

STUCCO		Residential				ICI				
Description: Removal or overcladding of 100% of the stucco siding.		Single Family	Multi-unit			Office		Institutional	Commercial	Industrial
			Low-rise	High-rise (rental)	High-rise (owner-occupied)	Rental	Owner-occupied			
Replacement Cycle										
Minnesota	years	75	65	35	35	35	35	35	35	na
Atlanta	years	25	20	20	20	20	20	20	20	na

MASS OF MATERIALS			DISPOSITION		
Material			Landfill	Recycle	Other
Base coat	kg/m ²	30.0	100%		
Finish coat	kg/m ²	6.0	100%		
Expanded metal mesh	kg/m ²	1.0	100%		
Fasteners	kg/m ²	0.028	100%		
Building paper (15# asphalt impregnated felt)	kg/m ²	2.295	100%		

Figure 9

3.7 End of Life Effects

The software uses a rather simple algorithm to discern the final disposition of building materials at the building's assumed end of life because it is difficult to forecast the state-of-the-art for material final disposition 60, 80 or 100 years in the future. Furthermore, legislation is constantly changing concerning construction and demolition waste.

The software first estimates the energy required to demolish the wood, steel or concrete structural systems of the building, then uses the calculated bill of materials at the building's end-of-life and determines the final disposition of these materials. The software assumes that those materials currently landfilled will continue to be landfilled, and those currently recycled or re-used will continue to be recycled and reused. All environmental burdens associated with recycling or reuse are a charge to the next use. For the materials assumed to be land filled, the software takes account of the energy use and related emissions associated with transportation to the landfill assuming typical distances to landfill for the region.