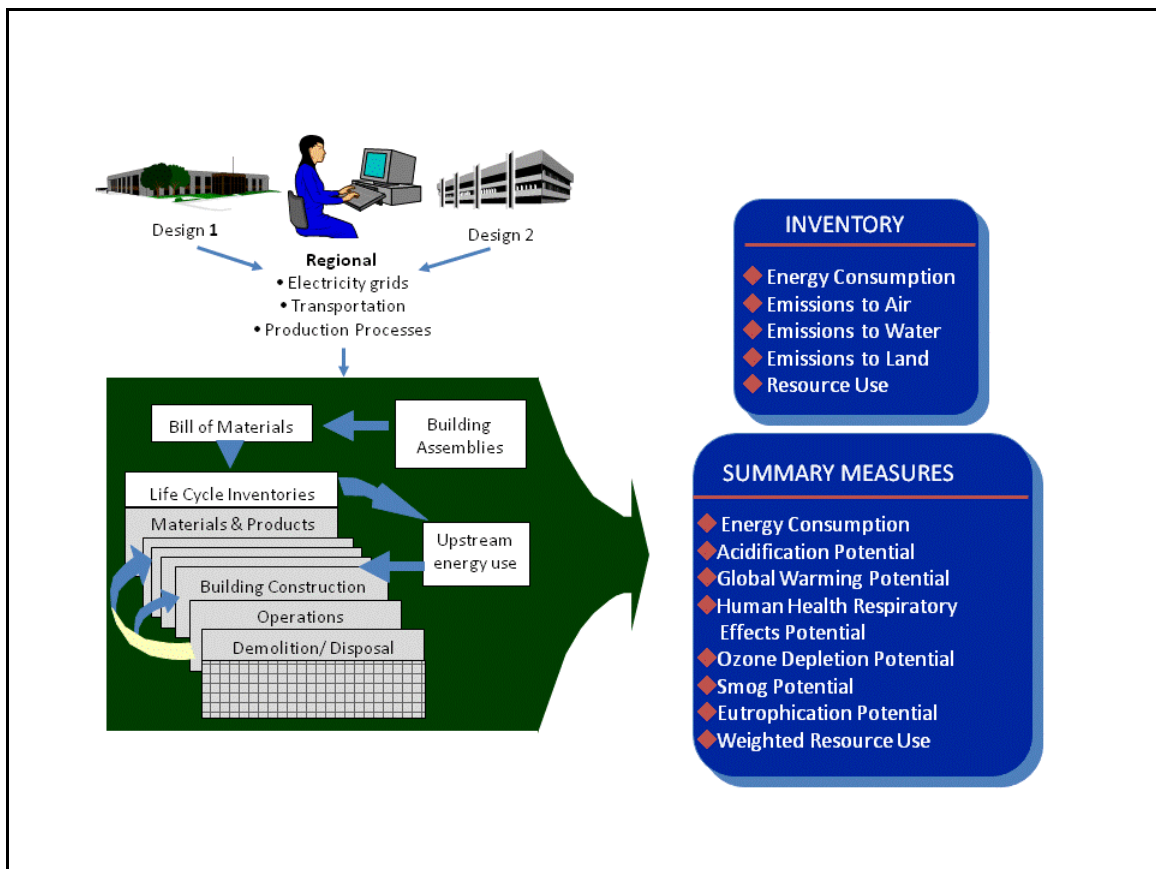


Athena Impact Estimator for Buildings V 4.1 Software and Database Overview



December 2010

1.0 Introduction

The goal of this document is to present an overview of the ATHENA[®] Impact Estimator software and underlying 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 design teams at the conceptual design stage of a project. The tool focuses on the conceptual stage because this is when key decisions are first made about the shape and material make-up of a building's structure and envelope. The Estimator takes comprehensive life cycle inventory information and makes it easily accessible so the team can make more holistic and informed environmental decisions about the design and material make-up of a proposed building.

This document 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 material and energy carrier LCI 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 C#. From time to time, this report touches upon new features and capabilities that have been added to the new version.

A "Reports & Publications" (Report CD info) is available free on our website. These reports typically relate to the underlying LCI data used in the software.

2.0 High Level Description

The Impact Estimator (IE) 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 environmental impact 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's environmental performance.

The model provides a cradle-to-grave Life Cycle Inventory (LCI) profile for a whole building over a user-selected service 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 Estimator also supports the following life cycle impact assessment measures, with all but the last using EPA Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) formulations:

- Global Warming Potential -CO₂ equivalent mass
- Acidification (Air) Potential - moles of H⁺ ions equivalent mass
- Human Health Respiratory Effects (air) Potential -PM_{2.5} equivalent mass
- Eutrophication (water) Potential - N equivalent mass
- Smog (air) Potential - NO_x equivalent mass
- Ozone Depletion (air) Potential – CFC 11 equivalent
- Fossil Fuel Consumption GJ – Total fossil fuel energy
- Weighted Resource Use - A valuation or weighed measure for resource extraction effects, where the weights reflect survey results on the relative environmental effects of extracting different resources.

The GWP measure does not account for sequestered carbon in any material.

The Weighted Resource Use measure has been retained pending the development of an internationally recognized measure of land use effects related to resource extraction. All of the remaining impact measures are either internationally accepted or are referenced measures in various international standards documents related to buildings and their evaluation (e.g., ISO 21930 & ISO 21931 and International Green Construction Code).

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 estimated 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 (e.g., insulation) with reductions in operating energy use.

3.2 Assembly and Material Considerations

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 1200 structural and envelope assembly combinations and is generally applicable to more than 90% of the typical North American building stock.

To add an assembly, the user starts with one of the basic structural systems listed below and can then build up a complete assembly system by adding cladding, insulation, barriers or other materials. Unlike Version 3 of the software, the user now has more flexibility to develop different assemblies with the same basic structural system, for example by having different cladding materials for different walls of the same type (ie, multiple claddings on wood walls). Version 4 also allows the user flexibility in choosing different performing windows types for different walls. The Estimator's column & beam structural system has been reconfigured to facilitate modeling of columns on the perimeter of the building or having the exterior wall provide the perimeter support instead of perimeter columns and four more column options are now available that were not supported in Version 3. Version 4 also now delineates floor from roof assemblies separately, instead of under the same sub-group as was the case in version 3.

The software has detailed LCI information for individual basic materials as well as for components such as trusses that are typically manufactured off-site.

Assemblies are currently disaggregated into groups and types — foundations, walls, floors, roofs, and columns and beams. A set of assembly types is represented within each assembly grouping (e.g., steel HSS columns with steel wide flange beams in columns & beams, and wood stud walls or steel stud walls within the wall assembly group).

Below is a list of the basic structural assemblies supported by the model; each of which can have many combinations depending on information entered by the user via input dialogue boxes.

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
Structural Insulated Panels

Beams and Columns

Wood Column
Hollow Structural Steel column
Concrete beam and/or column
Glulam beam and/or column
LVL/PSL beam and/or column
Wide flange beam and/or column
Wide flange beam and/or column (Gerber)
Mixed column and beam – mixed material system (e.g., LVL beam on concrete column)

Floors

Concrete suspended slab
Concrete parking garage – drop panel system
Concrete hollow core
Concrete pre-cast double "T"
Open web steel joist with "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)

Roofs

Concrete suspended slab
Concrete parking garage – drop panel system
Concrete hollow core
Concrete pre-cast double "T"
Open web steel joist with "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 below provides an example of the input dialogue box for a wood stud wall. You assign a name to the wall assembly, input the length and height, choose the wall type from the available assembly components.

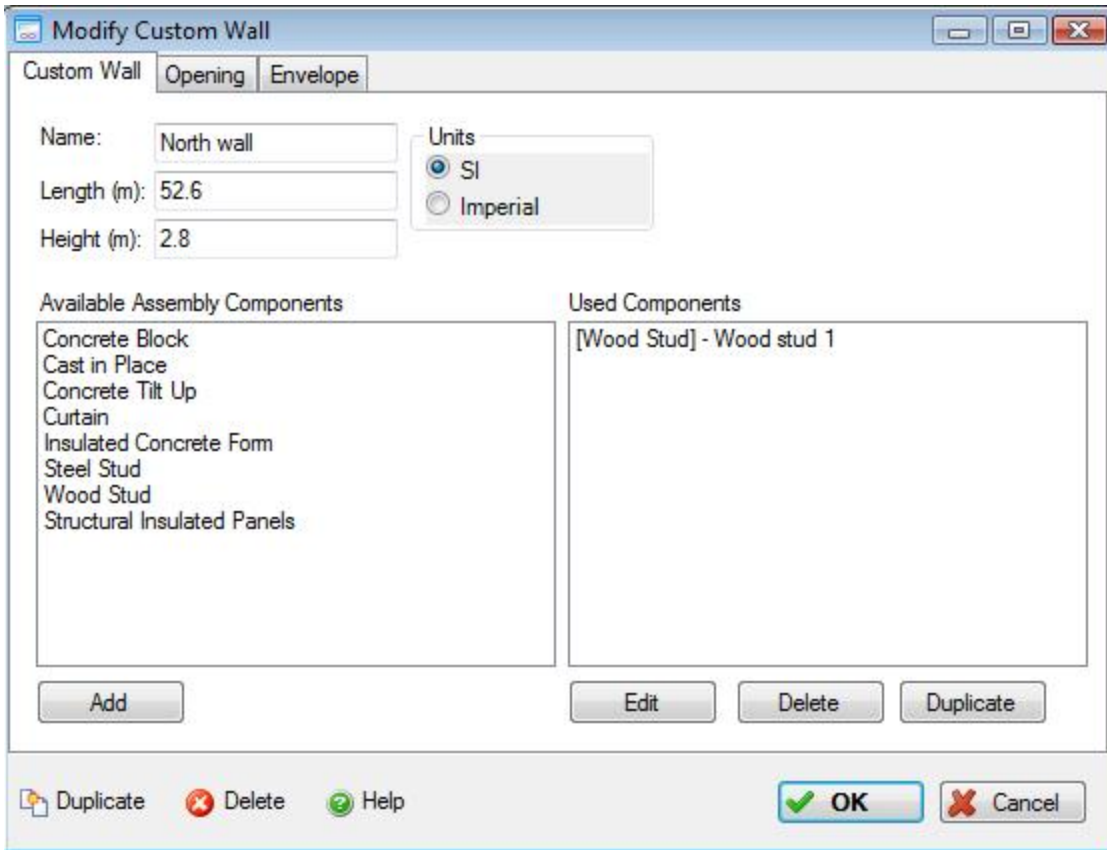


Figure 1

Figure 2 below allows user to specify the details of the wall assembly

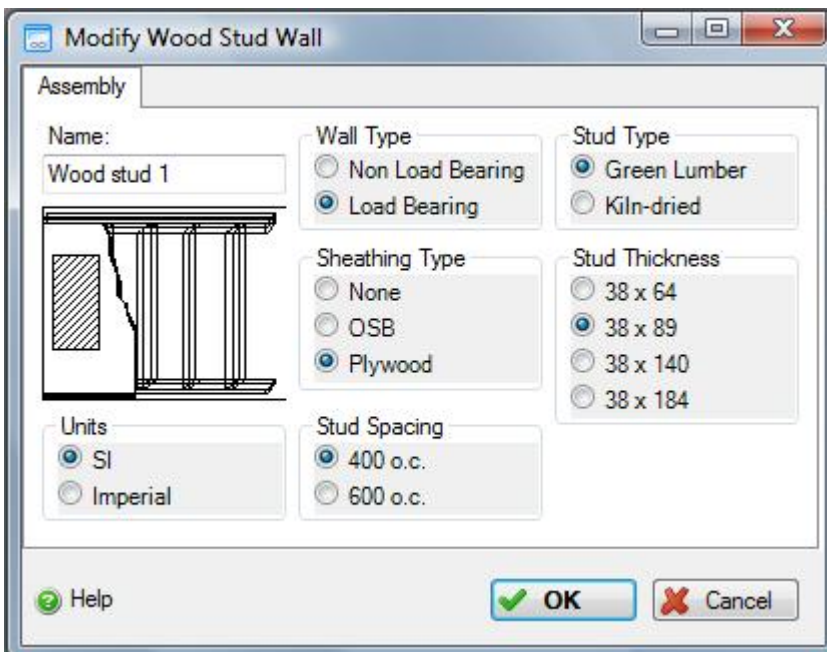


Figure 2

The user can also specify opening types and envelope configurations as shown in Figure 3.

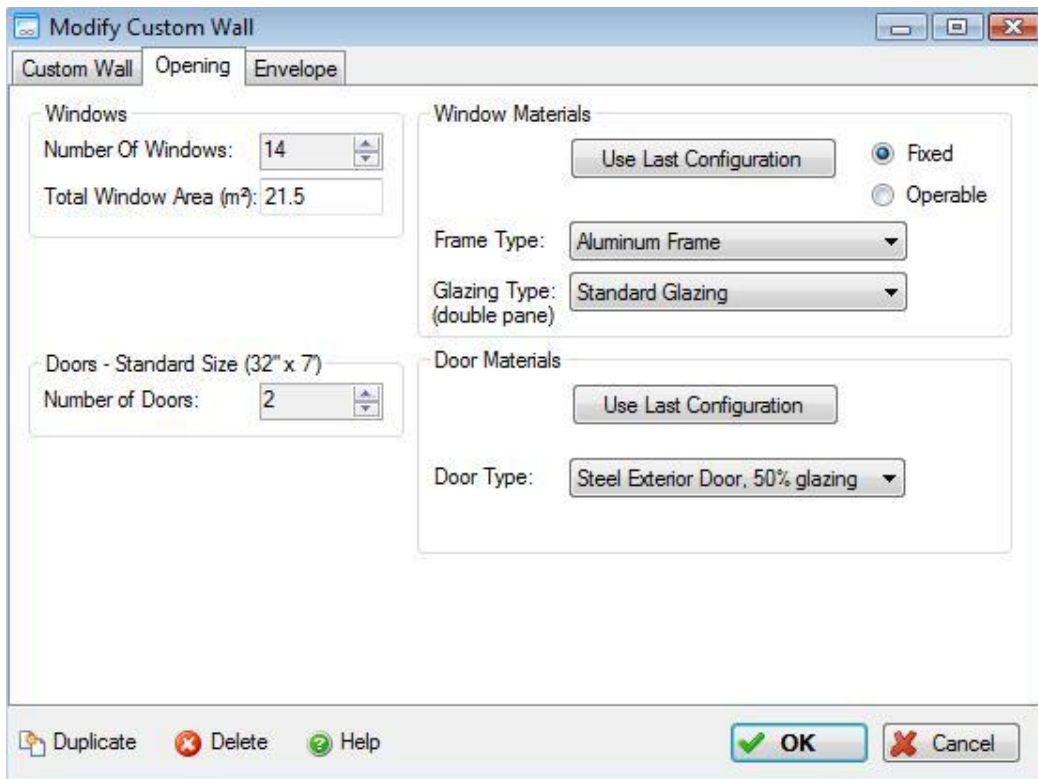


Figure 3

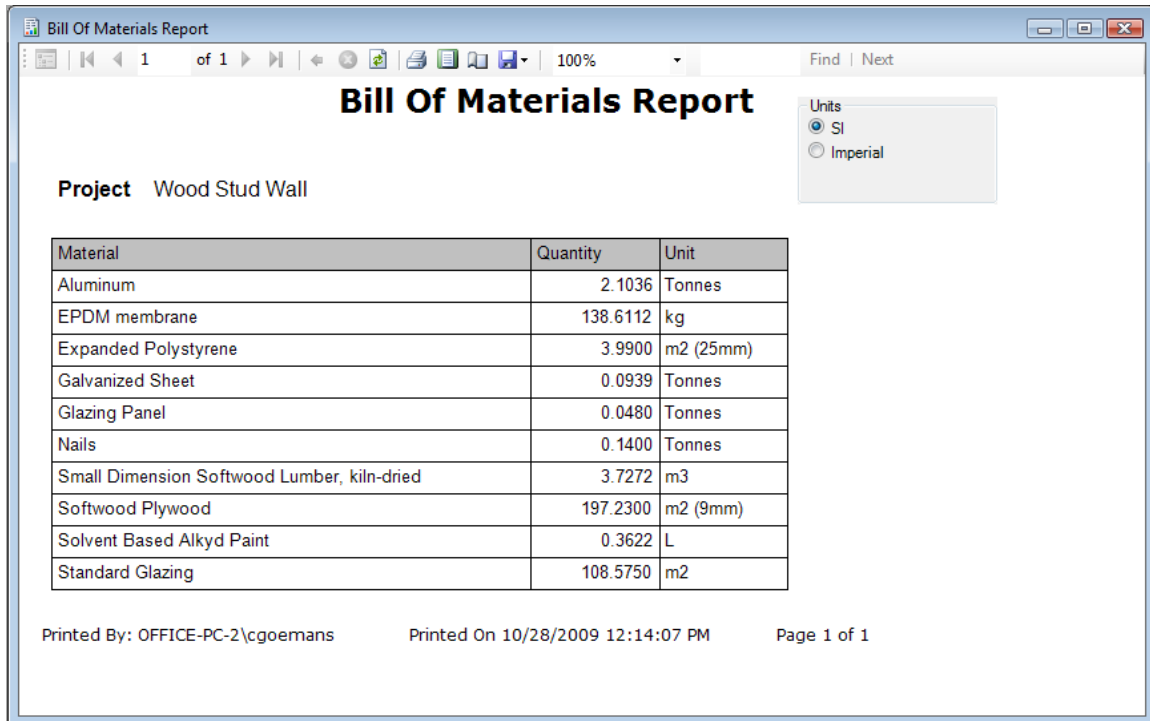
Non-structural, envelope materials are based primarily on the surface area of the specific assembly to which they are to be applied. For example, both insulation and gypsum board materials are added to an assembly on the basis of type and thickness and the Estimator determines the amount based on the 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 3*). 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 for doors has been developed and included in version 4. Doors are all considered to be a standard size (32"x84"), and there are 8 different door types available for different interior and exterior applications.

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 "wood stud wall" assembly by specifying its geometry (length and width) and its attributes –

e.g., sheathing type and stud spacing (see *Figure 2*)

The model then calculates the amount of wood and nails and adds them to determine a “bill of materials” (*Figure 4*).



Bill Of Materials Report

Project: Wood Stud Wall

Units: SI Imperial

| Material | Quantity | Unit |
|---|----------|-----------|
| Aluminum | 2.1036 | Tonnes |
| EPDM membrane | 138.6112 | kg |
| Expanded Polystyrene | 3.9900 | m2 (25mm) |
| Galvanized Sheet | 0.0939 | Tonnes |
| Glazing Panel | 0.0480 | Tonnes |
| Nails | 0.1400 | Tonnes |
| Small Dimension Softwood Lumber, kiln-dried | 3.7272 | m3 |
| Softwood Plywood | 197.2300 | m2 (9mm) |
| Solvent Based Alkyd Paint | 0.3622 | L |
| Standard Glazing | 108.5750 | m2 |

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Figure 4

The user defines envelope material layers applicable to the assembly (e.g., gypsum board, vapor barrier and insulation by type and thickness as in *Figure 5*).

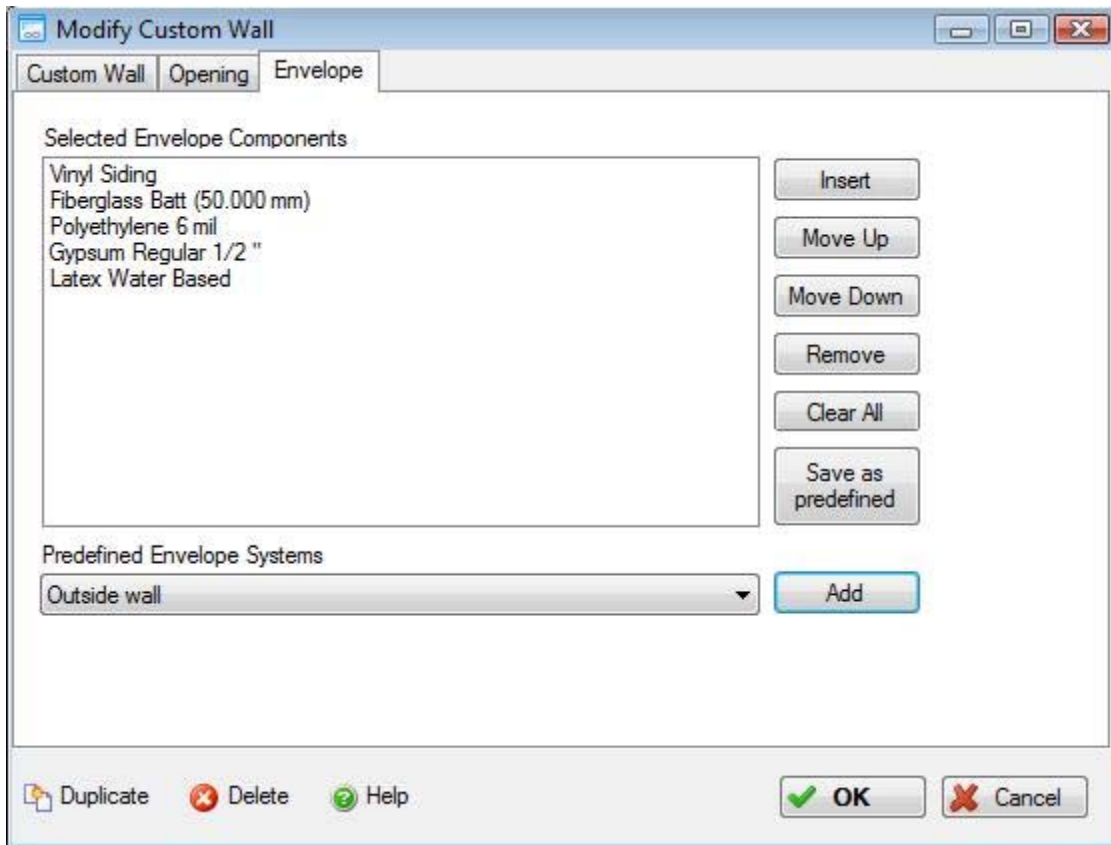


Figure 5

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 6*). 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.

Bill Of Materials Report

Project Wood Stud Wall

| Material | Quantity | Unit |
|---|----------|-----------|
| 1/2" Regular Gypsum Board | 155.3548 | m2 |
| 6 mil Polyethylene | 149.8185 | m2 |
| Aluminum | 2.1036 | Tonnes |
| EPDM membrane | 138.6112 | kg |
| Expanded Polystyrene | 580.6840 | m2 (25mm) |
| Galvanized Sheet | 0.0939 | Tonnes |
| Glazing Panel | 0.0480 | Tonnes |
| Joint Compound | 0.1550 | Tonnes |
| Nails | 0.1502 | Tonnes |
| Paper Tape | 0.0018 | Tonnes |
| Small Dimension Softwood Lumber, kiln-dried | 3.7272 | m3 |
| Softwood Plywood | 197.2300 | m2 (9mm) |
| Solvent Based Alkyd Paint | 0.3622 | L |
| Standard Glazing | 108.5750 | m2 |

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Figure 6

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 7 below)

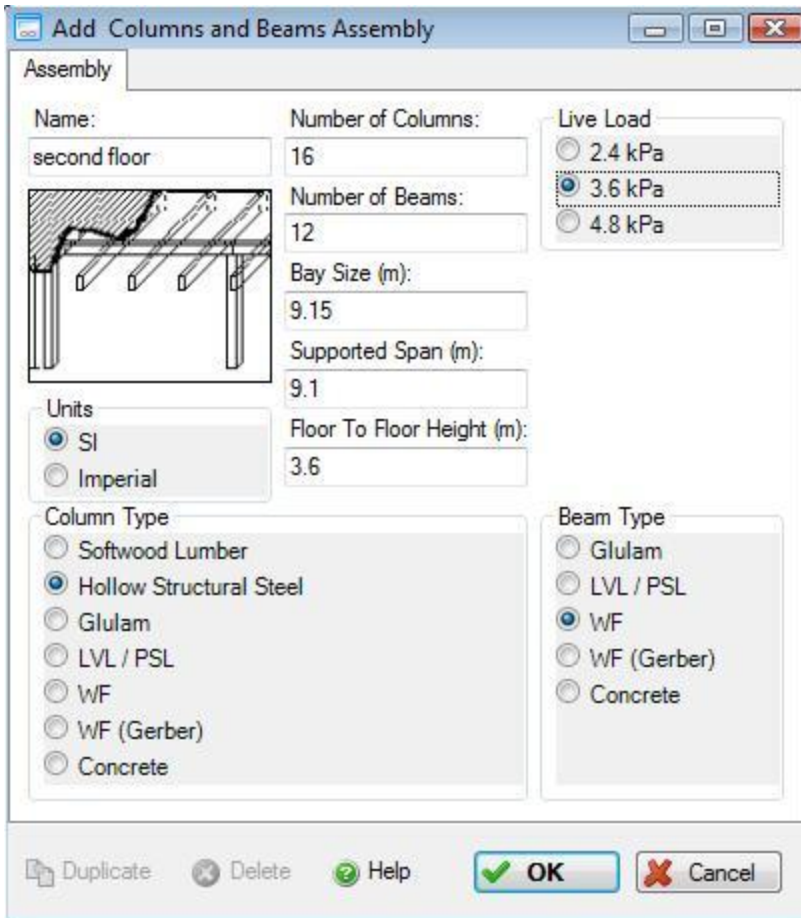


Figure 7

The graphic below (Figure 8) shows the basic material sizing calculation information used for a steel wide flange beam for a given bay size.

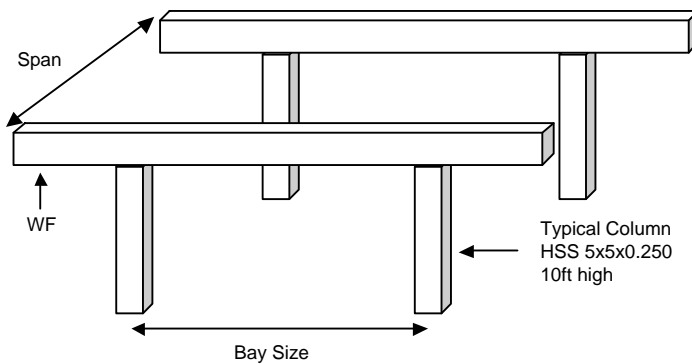


Figure 8

Figure 9 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 Estimator, 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.

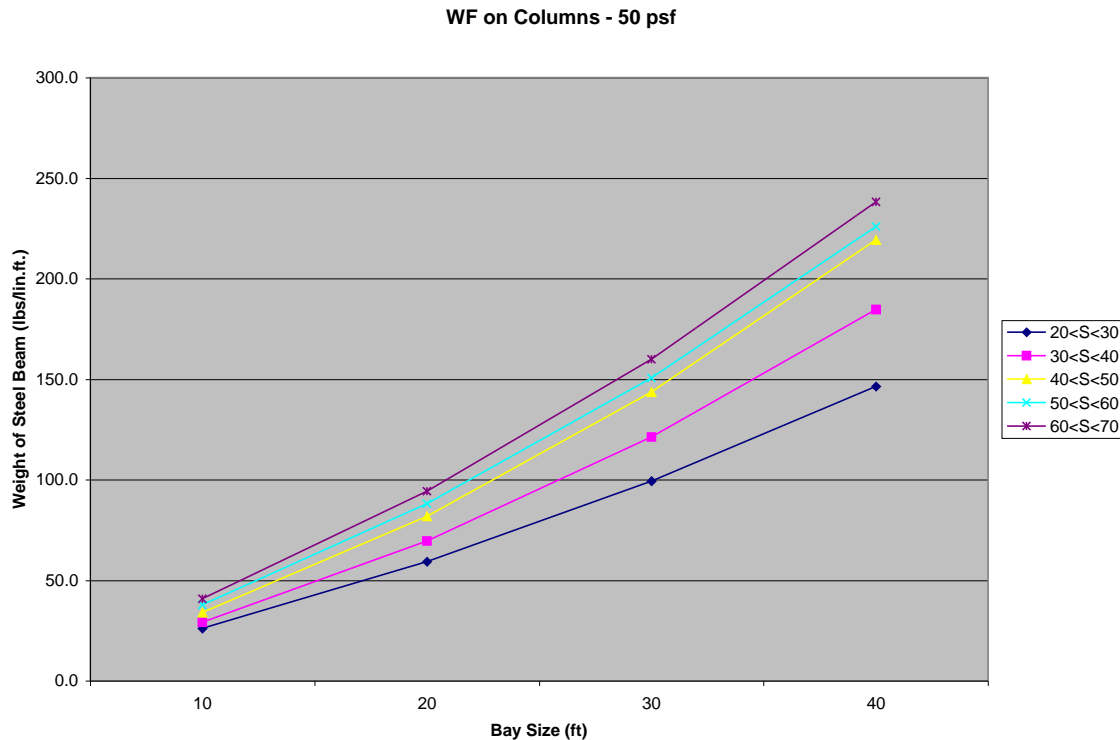


Figure 9

The 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 software 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, New York City, Pittsburgh, Minneapolis, Atlanta and Orlando are included. US regional coverage has since been expanded to include Seattle and Los Angeles (two seismic zones). The cities of Washington, D.C. and Phoenix with additional supporting regions are 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 is a self-sufficient generator of electricity or whether it draws electricity from the 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. Since Quebec is a self-sufficient generator of electricity, we therefore use the Quebec grid for electricity use in that region. For other regional locations some of the electricity may come from the larger interconnected grid, in which case the software uses data from both the region and from the interconnected grid. For example, the region represented by Atlanta is the Eastern North America grid intertie. More traditionally, Atlanta belongs to the Southeast Electric Reliability Grid (SERC). Georgia is not a self-sufficient generator of electricity. Consequently, a composite of the Georgia grid and Eastern North America grid intertie are proportionally combined and used by the model 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. Due to new power wheeling agreements across North America, the Institute has integrated the three major interconnection grids- Eastern, Western and Texas- as the basis for electricity usage in Version 4 of the model. However, provinces and states that are deemed net exporters of electricity to the grid 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 2007 US 2007 | <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 2009 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 updated in 2006. Resource harvesting profile updated in 2009 Institute report available for Canadian cradle-to-gate profile. |

| Product | Vintage | Comments |
|---|-----------------------------|---|
| | | <ul style="list-style-type: none"> • 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 updated in 2006. • Resource harvesting profile updated in 2009 • 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. • 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. Cedar siding data updated in 2009 • 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 | | |
| Claddings | CDN -various US -various | |
| Sheet steel cladding residential Sheet steel cladding commercial | | <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. |
| 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. • Canadian data Updated in 2009 |
| Concrete brick and split faced block | | <ul style="list-style-type: none"> • Canadian concrete brick data developed in 1998. |

| Product | Vintage | Comments |
|---|------------------------|--|
| | | <ul style="list-style-type: none"> 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 2009. PVC polymer portion to reflect new 2007 ACC data See US LCI database (www.nrel.gov/lci) for data |
| Fiber Cement Siding | | <ul style="list-style-type: none"> Originally developed in 2009. |
| Natural Stone | | <ul style="list-style-type: none"> Developed in 2009 from a secondary data source. |
| 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"> Added in 2007 based on polypropylene profiles |
| Mineral Wool | | <ul style="list-style-type: none"> Originally developed in 1998 and updated in 2002. Styrene polymer portion reflects 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. |
| Concrete tile | | |

| Product | Vintage | Comments |
|--|------------------------|--|
| | | <ul style="list-style-type: none"> Institute report available |
| 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 EPDM black updated in 2009 and EPDM white added. |
| 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 2011 Updated quantity take-offs in 2010 PVC and wood windows. |
| 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 structural elements of the building and the emissions to air, water and land associated with the on-site construction activity. Below, we use the example of pouring a cast-in-place concrete wall assembly to illustrate the calculation of on-site construction effects.

Pouring a cast-in-place wall typically consists of assembling the form work and placing reinforcing rebar in the forms and around openings, then pouring concrete in to the forms.

The forms may be moved about the site by forklift or crane and may be assembled by hand or crane for large scale formwork. Rebar might be placed around the site using forklifts or cranes and would typically be assembled by hand. The concrete will arrive on site in a concrete truck and will be poured using a concrete pump or a crane and bucket. Both concrete and rebar are assumed to make a 40 km round trip from mixing plant or distributor to the building site.

On site waste for concrete is estimated at 5%, and consists of any spillage from the forms and the dumping of excess concrete not required on site.

Form work is re-used until its degradation adversely affects the surface finish of the concrete work. On average, a 10% loss of material can be assumed after each use.

A wall might also need temporary heating for concrete curing. It is difficult to estimate whether or not a wall may be poured in sub zero

weather, as such, a proportion of the energy needed has been factored into the construction equal to the proportion of the year that the temperature falls below 0°C.

3.7 Maintenance, Repair and Replacement Effects

Maintenance and repair effects of building materials exposed to the elements or to wear (e.g., asphalt shingles) 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. Maintenance repair and replacement schedules for envelope elements have also been developed for each region supported by the software.

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 environmental burden of the window.

Using stucco as an 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 10 below.

| STUCCO | | Residential | | | | ICI | | | | |
|--|-------|---------------|-------------------|--------------------|----------------------------|--------|----------------|---------------|------------|------------|
| Description: | | Single Family | Multi-unit | | | Office | | Institutional | Commercial | Industrial |
| Removal or overladding of 100% of the stucco siding. | | | Low-Rise (rental) | 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 10

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, the legislation is constantly changing concerning the disposition of construction and demolition waste.

The software first estimates the energy required to demolish the wood, steel or concrete structural systems of the building (it is assumed that the envelope materials are demolished during the structural demolition, but have little influence on the demolition energy use. The software then calculates the 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 and reports these for the building project in question.