Athena
Sustainable Materials
Institute

Athena EcoCalculator for Commercial and Residential Assemblies: Inner Workings Synopsis

Athena
EcoCalculator
for Commercial Assemblies

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TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
COLUMNS & BEAMS	0	0	0	0	0	0	0
WHOLE BUILDING TOTAL	0	0	0	0	0	0	0

B. COLUMNS AND BEAMS (other assembly tabs at bottom of spreadsheet)

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	ASSEMBLY TYPE Column / Beam	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft² (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across all column and beam systems:				**42.26**	**2.82**	**0.86**	**7.23**	**2010**	**0.01**	**109.12**
METHOD 1 (ASSUMES NON-LOAD-BEARING EXTERIOR WALL)										
1	Concrete column / Concrete beam	0.0		115.09	9.02	2.55	24.68	5,255.05	0.05	396.78
2	Concrete column / Glulam beam	0.0		57.28	3.94	1.20	13.81	2,602.44	0.01	155.62
3	Concrete column / LVL beam	0.0		56.16	3.86	1.16	10.18	2,643.89	0.01	150.29
4	Concrete column / WF beam	0.0		96.62	5.81	1.85	11.70	5,425.94	0.01	221.59
5	HSS column / Glulam beam	0.0		17.41	1.09	0.37	6.44	476.12	0.00	35.69
6	HSS column / LVL beam	0.0		16.27	1.01	0.33	2.81	517.49	0.00	30.34
7	HSS column / WF beam	0.0		56.64	2.95	1.02	4.33	3,299.20	0.00	101.62
8	Precast Concrete column / Precast Concrete beam	0.0		38.78	3.68	0.94	6.23	1,114.74	0.01	147.67
9	WF column / Glulam beam	0.0		16.10	1.00	0.34	6.31	524.22	0.00	35.63
10	WF column / LVL beam	0.0		14.96	0.92	0.30	2.68	565.59	0.00	30.29
11	WF column / WF beam	0.0		55.33	2.86	0.99	4.20	3,347.30	0.00	101.56
	METHOD 1 TOTAL SQUARE FOOTAGE	0.0								
METHOD 2 (Assumes LOAD-BEARING exterior wall)										
12	Concrete column / Concrete beam	0.0		87.68	6.93	1.95	19.05	3,967.31	0.04	306.08
13	Concrete column / Glulam beam	0.0		40.35	2.77	0.85	10.15	1,796.20	0.01	108.73
14	Concrete column / LVL beam	0.0		39.44	2.70	0.81	7.18	1,830.11	0.01	104.37
15	Concrete column / WF beam	0.0		72.54	4.29	1.38	8.43	4,106.04	0.01	162.72
16	HSS column / Glulam beam	0.0		13.65	0.86	0.29	5.22	372.72	0.00	28.44
17	HSS column / LVL beam	0.0		12.71	0.79	0.26	2.25	406.57	0.00	24.07
18	HSS column / WF beam	0.0		45.74	2.38	0.82	3.49	2,682.22	0.00	82.40
19	Precast Concrete column / Precast Concrete beam	0.0		32.02	3.06	0.78	5.21	901.98	0.01	124.01
20	WF column / Glulam beam	0.0		12.77	0.80	0.27	5.13	404.92	0.00	28.40
21	WF column / LVL beam	0.0		11.83	0.73	0.24	2.16	438.77	0.00	24.03
22	WF column / WF beam	0.0		44.87	2.32	0.80	3.41	2,714.42	0.00	82.36
23	Pre-Engineered Building System	0.0		17.79	1.03	0.27	1.25	831.78	0.00	27.10
	METHOD 2 TOTAL SQUARE FOOTAGE	0.0								

September, 2012

1.0 Introduction

The goal of this document is to present an overview of the ATHENA® EcoCalculator for both Commercial and Residential Assemblies by providing an indication of the inner workings of the tool – what it does and how it does it.

The EcoCalculator is a free Life Cycle Assessment (LCA) tool that provides environmental impacts for common building assemblies. The commercial version was originally commissioned by the Green Building Initiative for use in its Green Globes assessment and rating system, where it is provided in the form of a credit calculator. The tool was developed by the Athena Institute in association with the University of Minnesota and Morrison Hershfield Consulting Engineers. In 2010, the APA commissioned a residential version.

The free generic versions of the EcoCalculator, without credit calculation functions, can generate instant LCA results because each pre-defined assembly has already been assessed using the ATHENA® Impact Estimator for Buildings – the parent software. The Impact Estimator, in turn, uses datasets first developed by the Athena Institute and constantly updated over 15 years, as well as data from the U.S. Life Cycle Inventory Database (www.nrel.gov/lci).

A similar Inner Workings Synopsis document for the Impact Estimator for Buildings is available on the Athena Institute website at the following url:
< http://www.athenasmi.org/wp-content/uploads/2011/10/ImpactEstimatorSoftwareAndDatabaseOverview.pdf>, This document is fundamental to a full understanding of the EcoCalculator in view of the Impact Estimator's parent role, and should be referenced for more detailed background information on key factors and considerations underlying the EcoCalculator's assumptions and calculations.

2.0 High Level Description

The EcoCalculator is a decision support tool, not a scoring or rating system. The tool indicates the environmental implications of pre-defined assemblies that have been assessed using the Impact Estimator and presented as a profile.

The EcoCalculator can be used for new construction projects, retrofits or major renovations, and for residential designs, either to compare specific assemblies or to assess all of the assemblies in a structure. The EcoCalculator is regionalized; users select the North American city that best represents the location and/or climate of their building site, or a USA average. In the commercial version, users also choose a low-rise or high-rise version, depending on the building in question.

The results take into account all life cycle stages: resource extraction and processing; product manufacturing; on-site construction of assemblies; all related transportation; maintenance and replacement cycles over an assumed building service life of 60 years; and structural system demolition and transportation to landfill of those materials that are currently landfilled.

There are seven types of building assemblies included in the EcoCalculator:

- Foundations and footings
- Columns and beams
- Intermediate floors
- Exterior walls
- Windows
- Interior walls
- Roofs

The list of assemblies represents common practices based on existing references and consultation with industry representatives and other stakeholders. The number of assemblies available is limited by two factors:

1. LCA data is not available for some materials.
2. The desire to make the EcoCalculator easy to use means not showing every possible variation within each assembly type (e.g., instead of showing LCA results and ratings for every type of rigid insulation on roof and wall assemblies, a generic representative “rigid insulation” is shown).

Sensitivity studies were done to ensure that the variation between products that fall within a generic definition is not significant.

The number of assemblies in each category varies widely depending on the possible combinations of layers and materials. In the Commercial Assemblies version, within the exterior wall category, for example, there are nine basic wall types, seven cladding types, three sheathing types, four insulation types and two interior finish options. The number of assemblies for exterior walls represents all viable combinations of these options, resulting in 76 wall assemblies for low-rise structures, and 41 wall assemblies for high-rise structures. This, however, is a small representation of the many more permutations or combinations of structure and envelope that are possible in the ATHENA® Impact Estimator for Buildings, where the user can customize his or her assemblies if those presented in EcoCalculator do not represent their design choices.

Assemblies are currently assessed in terms of a limited range of performance measures: global warming potential, embodied fossil fuel consumption, and pollution to air and water using EPA TRACI measures. It should be noted here that GWP does not account for sequestered carbon in any product, wood, steel or concrete.

To develop results, the user indicates the square footage represented by selected assemblies. Users can evaluate multiple assembly types within a category (e.g., exterior walls), in which case their impact measurements will be combined to arrive at a total environmental impact for that category. The EcoCalculator calculates and shows the percentages accounted for by selected assemblies within a category to assist the user. For Example, for columns and beams the EcoCalculator assumes the supported area is equal to the floor area immediately above the column and beam system; for exterior walls a window-to-wall ratio is assumed (20% for Residential and 40% for commercial) and structural allowance have been accounted for in the modeling of window systems.

Design results are presented in tabular form and show real time changes as the inputs are adjusted by the user. This allows different assembly options to be considered in light of their environmental impacts and provides the information necessary to make informed, scientifically based choices.

3.0 Inner Workings

3.1 Overview

The spreadsheet displays a selection of assembly category tabs along the bottom of the page (columns and beams, roofs, windows, exterior walls, etc.,) In the Figure 1 example below, Columns and Beams is the assembly category tab chosen.

Athena EcoCalculator for Commercial Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
COLUMNS & BEAMS	0	0	0	0	0	0	0
WHOLE BUILDING TOTAL	0	0	0	0	0	0	0

B. COLUMNS AND BEAMS (other assembly tabs at bottom of spreadsheet)

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	ASSEMBLY TYPE Column / Beam	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft² (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across all column and beam systems:				32.75	2.13	0.66	5.99	1523	0.00	81.06
METHOD 1 (ASSUMES NON-LOAD-BEARING EXTERIOR WALL)										
1	Concrete column / Concrete beam	0.0		115.09	9.02	2.55	24.68	5,255.05	0.05	396.78
2	Concrete column / Glulam beam	0.0		57.28	3.94	1.20	13.81	2,602.44	0.01	155.62
3	Concrete column / LVL beam	0.0		56.16	3.86	1.16	10.18	2,643.89	0.01	150.29
4	Concrete column / WF beam	0.0		96.62	5.81	1.85	11.70	5,425.94	0.01	221.59
5	Glulam column / Glulam beam	0.0		13.81	0.88	0.30	6.27	375.15	0.00	31.51
6	Glulam column / LVL beam	0.0		12.66	0.80	0.26	2.64	416.52	0.00	26.17
7	Glulam column / WF beam	0.0		53.03	2.74	0.95	4.16	3,198.23	0.00	97.44
8	HSS column / Glulam beam	0.0		17.41	1.09	0.37	6.44	476.12	0.00	35.69
9	HSS column / LVL beam	0.0		16.27	1.01	0.33	2.81	517.49	0.00	30.34
10	HSS column / WF beam	0.0		56.64	2.95	1.02	4.33	3,299.20	0.00	101.62
11	LVL column / Glulam beam	0.0		13.78	0.88	0.30	6.18	376.36	0.00	31.38
12	LVL column / LVL beam	0.0		12.64	0.80	0.26	2.55	417.73	0.00	26.04
13	Precast Concrete column / Precast Concrete beam	0.0		38.78	3.68	0.94	6.23	1,114.74	0.01	147.67
14	Softwood column / Glulam beam	0.0		13.67	0.88	0.30	6.18	381.08	0.00	31.21
15	Softwood column / LVL beam	0.0		12.53	0.80	0.26	2.55	422.45	0.00	25.87
16	WF column / Glulam beam	0.0		16.10	1.00	0.34	6.31	524.22	0.00	35.63
17	WF column / LVL beam	0.0		14.96	0.92	0.30	2.68	565.59	0.00	30.29
18	WF column / WF beam	0.0		55.33	2.86	0.99	4.20	3,347.30	0.00	101.56
	METHOD 1 TOTAL SQUARE FOOTAGE	0.0								

Figure 1

For each assembly category tab, the table is subdivided into two parts: a two-line comparison section at the top, showing the total impacts of the selected assembly tab by impact measure, as well as the whole building total for all assemblies chosen up to that point; and the actual assembly set, where the user inputs data and sees all the assemblies in the selected assembly group and the results per square foot for each assembly.

As can be seen in Figure 1, the sheet is divided into color-coded cells. The user chooses the assembly or combination of assemblies in a category that most closely approximates the proposed building, and enters the area of each selected assembly in the yellow cell next to that assembly. Results immediately appear in the top table. The EcoCalculator also calculates each entered assembly's percentage of the total for that category in the blue column. The blue cells in the top table instantly adjust to reflect the aggregated whole building results. If the user hovers the mouse pointer over the "Square Footage" cell at the top of the yellow column, an assembly drawing will appear, highlighting what area the user should be inputting in the yellow cells below.

Note that in the case of the columns and beams category, the square footage relates to the area of supported floor/roof plate, as illustrated in Figure 2 below.

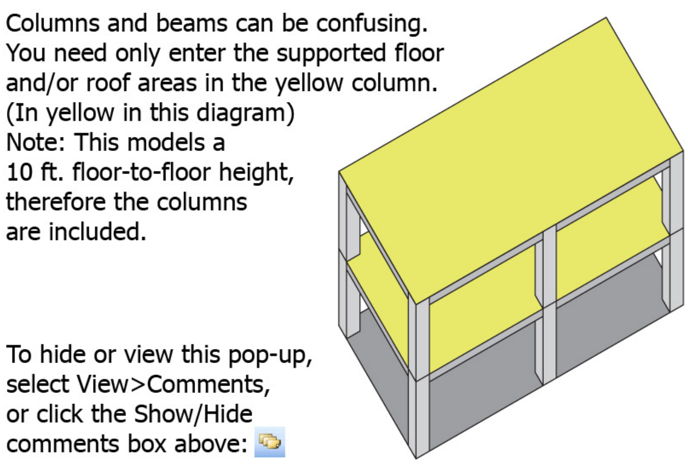


Figure 2

Color-coding

- ***Yellow*** denotes cells where users input the areas for selected assemblies, in square feet.
- ***Blue*** cells in the lower table show automatically calculated percentages of an assembly category accounted for by each selected assembly in that category.
- ***Blue*** cells in the upper small table show the automatically calculated total impacts by individual measure for all selected assemblies across all categories.
- ***Green*** cells show per square foot impact results from the Impact Estimator by individual measure for each assembly. *(Results are calculated in a whole building context. See Section 4.0 Considerations, Assembly Definitions, Assumptions and*

- *Impact Measures.) Note: In the residential version, the Fossil Fuel Consumption and Global Warming Potential columns have been highlighted in pink.*
- ***White*** cells in the upper small table show the total impact by individual measure for each assembly category, automatically calculated by multiplying square footages by per square foot impact results for all selected assemblies.
- ***Grey*** cells directly above the column of green cells for each measure show the average performance for that assembly category (e.g., for all exterior walls). This allows different assemblies to be compared to the typical average assembly at a glance, with results lower than the average being preferable.

Directly above the column of green cells for each measure (e.g., for global warming potential), there is a grey cell that shows the average performance for that assembly category (e.g., for all exterior walls). This allows different assemblies to be compared to the typical average assembly at a glance, with results lower than the average being preferable.

Figure 3 below shows the summary sheet, where the results from each assembly group and the whole building totals are displayed (summary tab). The percentages of each assembly group for each impact measure are shown in the table on the right, and in graphical form at the bottom of the figure.

Athena EcoCalculator for Commercial Assemblies

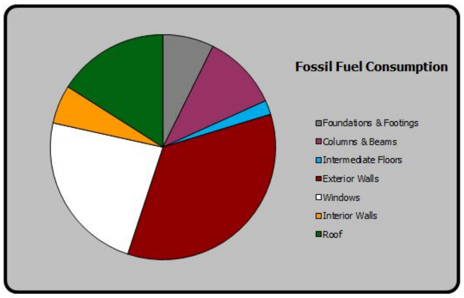
Version 3.7
Location: Atlanta
ASHRAE climate zone 3
Low-rise structures (Up to 4 stories)

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	Human Health Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	1,000	77,143	9	2,260	31	1,686	77	496
Columns & Beams	1,000	115,085	9	2,549	25	5,255	50	397
Intermediate Floors	1,000	21,475	2	508	12	1,063	0	62
Exterior Walls	3,000	366,745	30	10,194	85	6,579	192	1,492
Windows	500	246,570	22	17,062	321	4,295	105	1,751
Interior Walls	2,000	58,550	3	907	38	1,175	5	110
Roof	1,000	168,479	10	3,267	27	2,544	69	823
TOTALS		1,054,048	84	36,747	539	22,597	496	5,132

Percentages by assembly groups
(these results are shown in the pie charts below)

Fossil Fuel Consumption	Global Warming Potential	Acidification Potential	Human Health Criteria	Eutrophication Potential	Ozone Depletion Potential	Smog Potential
7%	11%	6%	6%	7%	15%	10%
11%	11%	7%	5%	23%	10%	8%
2%	2%	1%	2%	5%	0%	1%
35%	36%	28%	16%	29%	39%	29%
23%	26%	46%	60%	19%	21%	34%
6%	3%	2%	7%	5%	1%	2%
16%	11%	9%	5%	11%	14%	16%



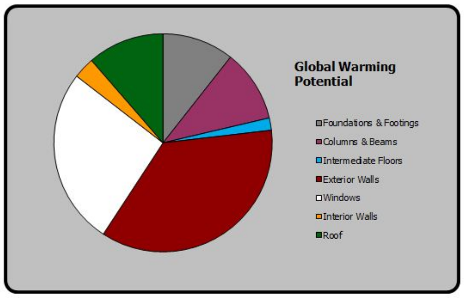


Figure 3

3.2 Regional Considerations

In the Impact Estimator, 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 climate and location of the building site.

This regionalization means that lists of assemblies reflect appropriate insulation values in different parts of the continent, according to ASHRAE 90.1 climate zones and corresponding insulation requirements.

The current versions of the EcoCalculator support the following regions:

- USA averages ASHRAE Zone 6
- USA averages ASHRAE Zone 3
- 8 Canadian regions:
    - Vancouver, Calgary, Winnipeg, Toronto, Ottawa, Montreal, Québec, Halifax
- 7 US regions:
    - Atlanta, Minneapolis, Orlando, Pittsburgh, New York City, Los Angeles, Seattle

Other Southwest and Central regions will be added in the future.

The environmental impacts of a building assembly will vary in different locations for several reasons; for example –

1 code requirements for insulation in wall and roof assemblies vary by region, as do building practices;
2 material sources and transportation distances vary by location; and
3 maintenance and replacement cycles can also vary.
4 in Vancouver, Seattle and Los Angeles, seismic requirements are taken into consideration, for example, a wood stud wall will include necessary sheathing nail patterns and tie downs while concrete block walls receive additional steel reinforcement and cavity mortar use

In an effort to be able to compare “equivalent assemblies” across different regions, wall and roof assemblies are modeled to meet insulation levels according to ASHRAE 90.1 climate zones for commercial assemblies and IECC 2009 guidelines for residential assemblies.. This can result in some curious situations where for instance a 2x6 wall cavity may not be completely filled with insulation, because doing so would exceed the MINIMUM requirement. Although this might not be the typical practice, it has been adopted for the purposes of modeling wall and roof assemblies in EcoCalculator in an effort to provide a comparison between different wall or roof systems of equal overall R-value. In some cases such as with Exterior Insulated Finishing Systems (EIFS) and wood stud walls, there is no ASHRAE requirement for exterior continuous insulation, but there is for cavity insulation. In this case, the amount of cavity insulation is applied in order to meet AHSRAE, and EIFS are applied as cladding, but it also adds an extra layer of continuous insulation. In this case, the overall R-value of the wall exceeds the ASHRAE minimum, and the LCA impacts will reflect that.

The LCA impact of a given assembly in a particular location does not vary much by building type. For example, one square foot of a concrete masonry interior wall has essentially the same LCA results whether that wall is used in a one-storey house or a 20-storey high-rise office building. The Impact Estimator allows the user to choose the building type (rental, owner occupied, single family etc.), which affects the maintenance and replacement schedules for roofing, cladding and windows. These schedules do not differ greatly from building type to building type, and as such, one building type was chosen, owner occupied office for the commercial version, and single family residential for the residential version as the archetype buildings in EcoCalculator.
Another area which may vary between building types is the window to wall ratio, and as such, a ratio of 40% was chosen as a median value across all commercial wall types and 20% was chosen across all residential wall types.

For every region, the EcoCalculator for Commercial Assemblies has both low-rise (four stories or less) and high-rise versions so that impact averages reflect appropriate assemblies within each category.

4.0 Considerations, Assumptions and Impact Measure Definitions

4.1 Considerations

In the development of specific LCA results for the EcoCalculator using the Impact Estimator, it is necessary to define assembly geometry and other structural characteristics, such as the length of an exterior wall or the live load on an intermediate floor. For example, commercial exterior walls are run using a 1,000 foot long, 10 foot high wall with a 40 percent window to wall ratio and residential exterior walls are run using a 30 foot long, 8 foot high wall with a 20% window to wall ratio. The results are presented on a per square foot basis in the EcoCalculator to make it easy for users to make visual comparisons among assemblies and with the averages for a category.

In the current version of the commercial EcoCalculator, estimated embodied effects were developed for EIFS cladding and pre-engineered building systems. The Impact Estimator does not yet fully support EIFS or pre-engineered building systems, therefore, estimates were made to approximate their environmental impact from first principles.

Similarly, in the residential EcoCalculator, estimated embodied effects were developed for wood and concrete piers, wood beams and EIFS cladding.

4.2 Assumptions

Global Assumptions

- The Impact Estimator requires a definition of building type, whether rental or owner occupied and expected life. This affects the maintenance schedule and repair/replacement of certain building assemblies. For the purposes of the commercial EcoCalculator, we assumed an “owner occupied office” building type, either high-rise or low-rise, with a 60-year life, and for the residential EcoCalculator we assumed a “single family residential” building type with a 60-year life
- An assumption was made that all assemblies would be installed in either low- or high-rise office or residential buildings using components and loadings typical for central areas of the United States but with differentiations between locations for the purposes of properly defining assemblies in terms of thermal performance and related code requirements.
- The life cycle stages considered in the LCA results include resource extraction, resource transportation, building product manufacturing and component manufacturing (components incorporate two or more building products), transportation from manufacturing plant to building site by various modes, on-site construction, maintenance and replacement of components over a 60-year period, end of life (demolition) effects for those materials replaced over the 60-year life and transportation to landfill of those materials currently landfilled.
- Commercial buildings’ exterior walls were assumed to have 40% windows by area and residential 20% windows by area.
- All windows were assumed to be inoperable in commercial buildings and operable in residential buildings.
- All window glazing was assumed to be double-glazing with low-E silver coating and argon filled cavity. Viewable curtainwall was assumed to be two panes of 6 mm glazing.
- All concrete (except floor topping) was assumed to be 4000 psi (30 MPa) in commercial buildings and 3000 psi (20MPa) in residential buildings.
- All cast-in-place concrete was assumed to contain 25% flyash in place of Portland cement; although this is not necessarily typical, it was considered more appropriate to use an environmentally beneficial formulation.
- All concrete masonry was assumed to contain 0% flyash.
- All gypsum board was assumed to be 5/8” thick regular gypsum board in commercial buildings and 1/2” thick regular gypsum board in residential buildings, taped and finished with two coats of latex paint.
- In commercial buildings, all wood structural panels (WSP) used data for softwood plywood, and in residential buildings plywood and OSB are available as decking and sheathing choices.
- All vapor barriers were assumed to be 6 mil polyethylene, and air barrier is assumed to be derived from a spun polypropolene derivative.
- All cavity insulation is modeled as fiberglass batt.

Foundations and Footings Assumptions

- Cast-in-place concrete walls were assumed to be 8" thick, with 4000 psi (30 MPa) concrete for commercial buildings and 3000 psi (20 MPa) for residential buildings. Both have 25% flyash content; #5 rebar reinforcement included; allowance for form-ties, wire, etc.
- Concrete masonry exterior walls were assumed to be standard weight, 8"x8"x16" hollow concrete blocks; every third vertical core was assumed to be grouted and reinforced with one steel bar.
- Concrete slab-on-grade are assumed to be 4" thick, 4000 psi (30 MPa) for commercial buildings and 3000 psi (20 MPa) for residential buildings, 25% flyash concrete with welded wire mesh reinforcement.
- Footings are assumed to be 4000 psi (30 MPa) with #5 rebar for commercial buildings and 3000 psi (20 MPa) with #4 rebar for residential buildings each with , 25% flyash content. The user is required to calculate the volume of his/her footing assembly and input the total volume of concrete in the EcoCalculator. This value should reflect local soil conditions

Column and Beam Assumptions

- Live load for structural systems was assumed to be 75 psf/3.6 kPa for commercial buildings and 50 psf/2.4 kPa for residential buildings.
- Commercial bay sizes were set at 30'x30' and residential at 10'x15' for the purpose of assessing columns and beams.
- Column heights were set at 10' for commercial assemblies and 8' for residential.
- Glulam beams assumed 24F grade (2400 psi allowable bending stress) beams.
- HSS steel columns assumed 5"x5" steel tube, ¼" tube thickness.
- Wood columns assumed 6"x6" (nominal) built-up columns.

Intermediate Floor and Roof Assumptions

- The live load for roofs was set at 50 psf (2.4 kPa).
- The live load for intermediate floors was set at 75 psf (3.6 kPa) for commercial buildings and 50 psf (2.4 kPa) for residential buildings
- Wood trusses were assumed to be 2"x4" or 2"x6" (nominal)/38 x 89 mm or 38 x 140 mm solid lumber fastened with galvanized steel nail plates. Trusses were assumed to be spaced at 24"/600 mm o.c. and bridging included at 6'-6"/2000 mm o.c.
- Open web steel joists were assumed to be 4'/1200 mm o.c.
- Precast double-T assemblies were assumed to be 8'/2400 mm wide.
- Steel joists were assumed to be 16 gauge steel "C" joists.
- Composite wood and steel joists (TJM, TJL, TJW and TJH type) were assumed to be 4'/1200 mm o.c. Joist chords were assumed to consist of one or two 2"x4"

(nominal)/38 mm x 89 mm wood members with tubular steel webs. Nails and other steel connectors except bridging are included.

- Wood I-joists were assumed to be ½” OSB web with either 2”x3” (nominal) LVL flanges for commercial buildings or 2”x2” (nominal) MSR flanges for residential buildings..
- Solid wood joists were assumed to be 2”x (nominal)/38 mm wood joists (SPF #2 grade) at 16”/400 mm o.c. and include solid lumber bridging at 6’-6”/2000 mm o.c
- Steel decking was assumed to be 22 ga. 1.56”/39 mm metal deck.
- Concrete topping assumed 3 ½”/89 mm thick concrete reinforced with 6”x6”/150 mm x 150 mm no. 10 metal mesh.
- EPDM roofing membrane assumed ethylene-propylene-diene monomer used as roofing membrane application density of 4.5 kg/m^2 or 92 lbs/square (100 sq.ft.).
- Modified bitumen roofing membrane assumes 2-ply roofing application density of 34 kg/m^2 or 695 lbs/square (100 sq.ft.).

Exterior Wall Assumptions

- Concrete masonry exterior walls were assumed to be standard weight, 8"x8"x16" hollow concrete blocks; every third vertical core was assumed to be grouted and reinforced with one steel bar.
- ICF exterior walls were assumed to be 8” in total thickness with a finished R-value of 20. 4000psi concrete with 25% flyash content was assumed; steel reinforcement included; wood sill plates and rough opening framing included. Concrete tilt-up walls were assumed to be 8” thick, with 4000psi concrete with average (25%) flyash content; #5 rebar reinforcement included; allowance made for CIP steel angle, lifting inserts/accessories, etc.
- Curtainwall assemblies assumed self-supporting grid comprising most of the exterior wall envelope area. Grid system was assumed to be aluminum (100 mm deep mullions) on 2 m centers vertically and 1.5 m horizontally. Provided take-off assumed every vertical mullion in the curtainwall is structurally connected via structural steel at every floor.
- Wood studs were assumed to be kiln dried, 2x6 (nom.). Double top plates (single top plates for interior non-load bearing walls) and a single bottom plate included. Fasteners included.   For residential buildings, there is also one extra corner or nailing stud included every 30 ft.
- Structural Insulated Panels are modeled on a 3 ½” expanded polystyrene core, with 2x4 lumber splines and framing, sheathed on both sides in 7/16” OSB.
- Steel studs were assumed to be 1 5/8” x 3 5/8” or 1 5/8” x 6” 20 ga. Studs, top and bottom tracks included; fasteners included. For residential buildings, there is also one extra corner or nailing stud included every 30 ft.
- Brick cladding was assumed to be standard 7.6"x 3.5"x 2.3" cored clay brick; includes brick ties and mortar.
- Steel cladding assumed 26 ga. galvanized steel siding for commercial buildings, and 30 ga. For residential buildings, each with one coat of latex paint.

- Stucco was assumed to be Portland cement based traditional stucco with steel mesh reinforcement. Galvanized flashing and 15# felt moisture barrier included.
- Vinyl cladding was assumed to include j-channels and 15# felt moisture barrier.
- Wood siding used data from beveled lap siding, pine for commercial buildings and cedar for residential buildings. One coat of latex paint included.
- Natural stone cladding assumes 0.5m x 0.5m x 0.03m slabs, including brick ties and mortar.
- Fiber cement siding includes #15 felt moisture barrier.
- Exterior wall rigid insulation was assumed to be polyisocyanurate foam board with foil facing at R-7 per inch, with thickness dependent on required R-value as per ASHRAE 90.1 for commercial buildings, and extruded polystyrene at R-5 per inch, with thickness dependent on required R-value as per 2009 IECC for residential buildings.
- All batt insulation in exterior walls was assumed to be fiberglass at R-3.13 per inch, with the thickness dependent on the required R-value per ASHRAE 90.1for commercial buildings and 2009 IECC for residential buildings..

Interior Wall Assumptions

- Interior concrete masonry walls were assumed to be 8" thick.
- Wood studs were assumed to be 2"x4", kiln dried. Non-load bearing walls (24" o.c.) include a single top and bottom plate, and load bearing walls (16" o.c.) include two top and one bottom plate; fasteners included.
- Steel studs were assumed to be 1 5/8" x 3 5/8". Non-load bearing walls (24" o.c.) are 25ga., and load bearing walls (16" o.c.) are 20ga. Top and bottom tracks and fasteners included.

4.3 Impact Measure Definitions

Fossil Fuel Consumption is reported in Mega-Joules (MJ) and includes all fossil fuel energy sources as calculated within the Impact Estimator, including direct and indirect fossil fuel use; used to transform or transport raw materials into products and buildings, and inherent fossil energy contained in raw or feedstock materials that are also used as common energy sources. For example, natural gas used as a raw material in the production of various plastic (polymer) products is included in fossil fuel consumption. In addition, the measure captures the pre-combustion (indirect) fossil energy use associated with processing, transporting, converting and delivering fuel and energy. It does not include any emerging energy sources, such as solar or wind energy, nor does it include nuclear or other renewable energy forms such as biomass or hydro energy.

Global Warming Potential (GWP) is an equivalence measure with carbon dioxide as the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO_2 equivalence effect", which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the difference in atmospheric reactivity or stability of the various contribution gases over time. The International Panel on Climate Change (2001) 100 year time horizon figures have been used here as a basis for the equivalence index:

CO_2 Equivalent kg = CO_2 kg + (CH_4 kg x 23) + (N_2O kg x 300)

The following five water and air pollution measures are based on the US EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts tool (TRACI).

Acidification Potential (AP) is a more regional rather than global impact affecting human health when high concentrations of NOx and SO_2 are attained. The AP of an air or water emission is calculated on the basis of its moles of hydron (H+) equivalence effect.

Aquatic Eutrophication Potential is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to a water body it leads to the proliferation of aquatic photosynthetic plant life. This may lead to a chain of further consequences ranging from foul odours to the death of fish. The calculated result is expressed on an equivalent mass of nitrogen (N) basis.

Human Health (HH) Criteria Air-Mobile. Particulate matter of various sizes (PM10 and PM2.5) have a considerable impact on human health. The EPA has identified "particulates" (from diesel fuel combustion) as the number one cause of human health deterioration due to their impact on the human respiratory system – asthma, bronchitis, acute pulmonary disease, etc. The Athena Institute used TRACI's "HH Criteria" characterization factor, on an equivalent PM10 basis, in our final set of impact indicators.

Ozone Depletion Potential (ODP) accounts for impacts related to the reduction of the protective ozone layer within the stratosphere caused by emissions of ozone depleting substances (CFCs, HFCs, and halons). The ozone depletion potential of each of the contributing substances is characterized relative to CFC-11, with the final impact indicator indicating mass (e.g., kg) of equivalent CFC-11.

Photochemical Ozone Formation Potential (Smog). Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The "smog" indicator is expressed on a mass of equivalent ozone (O_3) basis.