The Pennsylvania Housing Research Center

Life-Cycle Assessment Tools for Building Analysis

Research Brief: RB0511

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INTRODUCTION

A Life-Cycle Analysis (LCA) is a methodology to assess the total costs and environmental impacts of a product. LCA is especially useful when it comes to evaluating trade-offs between initial and operating costs. This builder brief will introduce four different LCA tools, and discuss the similarities and differences among these tools when applied to LCA of buildings.

Building Energy Consumption

Energy consumed by buildings represents a significant fraction of the total energy use in the world. In developed countries, energy consumption from buildings comprises 20% to 40% of the total energy use, and this percentage is higher than either industrial or transportation energy consumption in both European Union and United States. [1]. Therefore, building energy cost analyses is an important consideration. These analyses should be performed in early building design stages.

In a standard building design approach, building energy costs are typically estimated by load calculation and annual energy analysis software, such as DOE-2 [2] and EnergyPlus [3]. These methods are appropriate to analyze the building thermal loads and size the cooling or heating equipment. A building and building systems will consume a large amount of energy and money during their lifespan. The energy consumption during the entire lifespan should be considered when evaluating different building design solutions. Building operation and maintenance practices can play a significant role in this evaluation.

Life-Cycle Assessment (LCA)

Life-Cycle Assessment (LCA) is an effective way to help make informed investment decisions during the early building design stages. LCA is an analytical methodology for a systematic evaluation of the environmental impacts of a product or service system through all stages of its life cycle [4]. LCA evaluations include potential environmental impacts from raw material acquisition to production, use, and disposal. It takes into account all costs of constructing, owning, and disposing of a building or building system. LCA evaluations have been used in many industries and fields of research, and it is helpful to assess building products and assemblies in an integrated design process.

LCA evaluations for buildings can inform decisions regarding selection of different building systems. For example, improvements of building enclosure system will take additional capital investments, but will also bring significant net energy savings during the building lifespan. Without LCA, a decision maker is likely to ignore the benefit of these improvements and only focus on the initial costs. Moreover, LCA is especially useful when project alternatives that perform the same function, but differ with respect to the initial costs and operating costs, are to be compared in order to select the one that maximizes net savings. For example, LCA will help determine whether the incorporation of a high-performance HVAC or glazing system, which increases the initial costs, but results in greatly reduced operating and maintenance costs, is cost-effective or not. A lowest Life-Cycle Cost (LCC) is the most straightforward and an easy-to-interpret measure for economic performance.

LIFE-CYCLE ASSESSMENT TOOLS FOR BUILDINGS

A large number of life-cycle assessment tools are developed for designers and researchers to analyze the life-cycle cost of buildings. LCA tools for buildings measure the economic costs and environmental performance of building products and systems by using the life-cycle assessment approach specified in the ISO 14040 series of standards. The life-cycle stages of buildings include raw materials, manufacturing, transportation, use, and end of life. The following four tools are reviewed:

1. BEES
2. ATHENA EcoCalculator
3. ATHENA Impact Estimator
4. SimaPro

BEES: A Product-Level LCA Tool

The Building for Environmental and Economic Sustainability (BEES) software was developed by the U.S. Environmental Protection Agency (EPA) Engineering Laboratory. It is a useful methodology for selecting cost-effective, environmentally-preferable building products. It is available online via the BEES Online access to designers, builders, and product manufacturers. BEES Online includes actual environmental and economic performance data for two-hundred and thirty building products, which is sufficient for most of the analysis.

All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, as well as recycling and waste management. Economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental impacts of building products are analyzed using TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts). Environmental and economic performance data are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis.

To select environmentally-preferred, cost-effective building products, users need to follow three main steps:

1. Set the parameters

Weighting factors are an important input in BEES, used to combine different elements into a uniform scale of evaluation. Environmental impact weights are factors used to combine different environmental impacts in an evaluation. In the section on model setting of BEES, users can choose environmental impact category weights from three pre-defined weight-setting categories or define weights by selecting the user-defined weight set. Similarly, another weighting factor, performance weight, is introduced to integrate environmental performance and economic performance in BEES.

2. Select alternative building products

Information on different building products is built in the program, so that users can choose the products from the existing database. Two-hundred and thirty products are divided into seven major group elements.

3. View the BEES Online results

BEES Online produces graphs showing product scores. The larger the score, the worse the performance is for the selected building products.

ATHENA EcoCalculator: An Assembly-Level LCA Tool

The ATHENA EcoCalculator for assemblies includes a series of spreadsheets developed by the Athena Institute in association with the University of Minnesota and Morrison Hershfield Consulting Engineers. The tool provides instant LCA results for commonly used building structure and envelope assemblies. It is available free of charge with two versions: EcoCalculator for Commercial Assemblies and the new EcoCalculator for Residential Assemblies. The program covers information on hundreds of common building assemblies.

This calculator estimates the environmental effects of building materials and their related processes. It does not estimate or account for operational energy. It is intended to be used to quantitatively compare different types of building materials and assemblies. This calculator accounts only for environmental impacts, such as global warming potential, acidification potential, ozone depletion potential, HH respiratory effects potential, eutrophication potential, and smog potential, and do not include associated economic costs. To use EcoCalculator, following three main steps are needed:

1. Select and download the appropriate spreadsheet of EcoCalculator

Users have to download a suitable spreadsheet version by selecting the most appropriate climatic zone and the building height. These choices will affect the assembly definitions and characteristics.

2. Input relevant parameters

There are several assemblies covered in the each version of spreadsheets. After downloading a spreadsheet, user needs to select the assembly sheet from one of the categories: Exterior walls, Roofs, Intermediate floors, Interior walls, Windows, Columns and beams. The environmental impacts for each assembly have been built in the spreadsheets. Users only need to input the areas of assemblies into the yellow highlighted cells.

3. View the results

After step 2, the results will be automatically displayed in the blue highlighted cells. This tool determines the extended environmental effects of the materials used in a building based on eight impact categories. The summary of all assemblies' environmental impacts will show in the summary sheet.

ATHENA Impact Estimator (IE): A Whole-Building Level LCA Tool

In North America, the ATHENA Impact Estimator for Buildings, also developed by Athena Institute, is the only software that is particularly designed to evaluate whole buildings based on life-cycle assessment methodology. Using IE, architects, engineers, and others can assess and compare the environmental impacts of industrial, institutional, commercial and residential buildings. A trial version is available online for a short period use. The software is capable of modeling well over 1,000 structural and envelope assembly combinations. For an economic analysis, ATHENA IE can provide users with a report of material costs, listing the quantity of all the materials required in the building. The results of ATHENA IE focus on environmental impact of different buildings. In contrast to EcoCalculator analyses, an analysis undertaken by Impact Estimator includes the environmental effects from both building construction and operation.

To analyze building performance, users need to perform the following three main steps:

1. Start a new project

In this step, users need to define gross floor area and building life expectancy in the project, as well as select project location and building type.

2. Build a model in the project

Users can define building enclosure by selecting and adding various assemblies into the model. Each assembly can be modified by identifying relevant parameters. This is helpful in defining a more detailed model of a building according to the analysis requirements.

3. Report the results

IE can show a general report for the selected project with all the details of building performances. Furthermore, two or more projects can be compared in same graphs.

SimaPro: A Material-Level LCA Tool

SimaPro is a detailed LCA tool developed by PRé Consultants, which contains a number of impact assessment methods. SimaPro comes with a large set of data libraries coving 6,000 processes. The software covers all the details of life-cycle analyses. The software can be used to design analysis models in different fields of engineering. However, it takes much a more significant time investment for the users to learn to use the software. There are also tutorial lessons offered by PRé Consultants.

The steps of application can typically be divided into three parts: building model, assessment method selection, and result overview according to project requirements. Building a model in SimaPro is a tedious process because many details have to be set up. The software is relatively expensive, and it has specific computer memory requirements due to relatively complex computations.

CASE STUDIES

In order to compare performance of the reviewed LCA tools, this section presents several case studies. A few examples are also provided to directly compare the analysis results using different tools.

BEES

Using BEES, the performance of two or more products can be directly compared in one study. For example, the performance of an OSB-sheathed wall and plywood-sheathed wall are compared. Table 1 shows the main parameters assumed for this case study.

Table 1: Parameters in the case study

Parameters	Values
Area (ft2)	1
Building Life (yr)	50
Transportation Distance (miles)	500
Environmental Impact Weights	Equal Weights

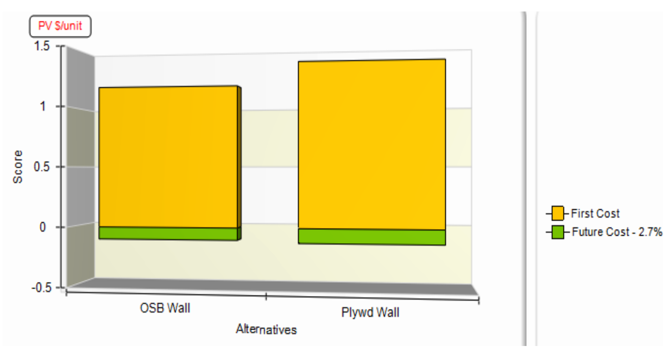

Figure 1: Economic performance

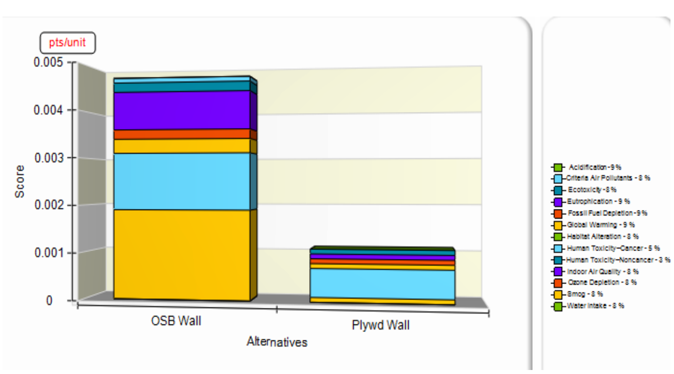

Figure 2: Environmental performance

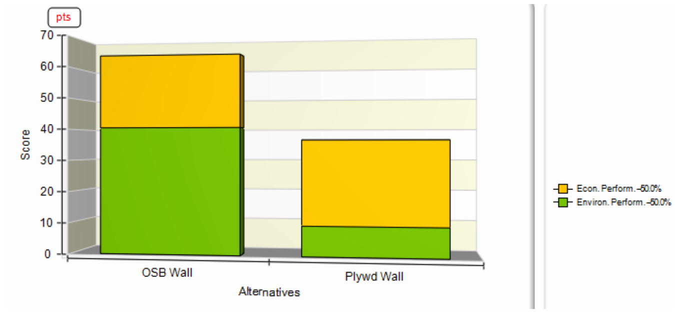

Figure 3: Comparison of the overall performance

Figures 1 through 3 show economic costs and environmental impacts with a lower score indicating lower cost or impact. In Figure 1, the percentage in the legend is the discount rate excluding inflation. In Figure 2, the percentages shown in the legend are environmental impact category weights. In Figure 3, performance weights are shown as the percentages in the legend. Per the discussion on BEES: a product-level LCA tool, all of these numbers could be set at the beginning of analysis.

In this case study, the economic performance of OSB Wall is better than Plywood Wall, which is shown in Figure 1. However, building owners might not care only about the economic analysis. Further BEES analyses indicate that the overall environmental performance of Plywood Wall is much better during the 50-year life cycle because of its lower environmental impacts as shown in Figures 2 and 3. In the environmental performance report, BEES gives a much more detailed breakdown of results than other LCA tools. For example, regarding global warming impact, there are CO2 equivalencies for every greenhouse gas listed in the BEES result. Other programs only provide the overall CO2 equivalent.

ATHENA Impact Estimator (IE)

ATHENA Impact Estimator (IE) is another good tool to compare two projects. In contrast to BEES, IE focuses on the analyses of a whole building rather than just materials themselves. To illustrate this, the authors created a model of a whole building with two different external wall types, OSB and Plywood, as shown in Table2.

Table 2: Parameters in the case study

Parameters	Case Study1	Case Study2
Area (ft^2)	48	
Building Life (yr)	50	
Foundation	Thickness: 4 in Concrete: 4000psi Fly ash: 25%	
Roof	Modify Wood I Joist Roof Decking thickness: 5/8in Decking Type: OSB Live Load: 50 psf Wood-I Joist: ½" thick OSB webs, and 2.5" x 1.5" LVL flanges	
Walls	OSB Walls	Plywood Walls

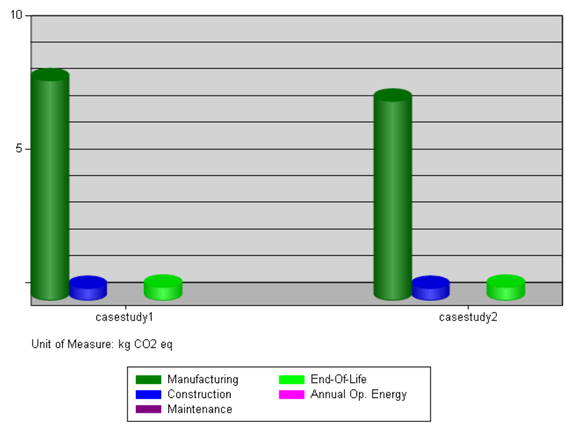

Figure 4: Comparison of global warming potential by life-cycle stages

Figure 4 presents IE results for the building with two different wall types. Instead of listing only the overall CO2 equivalent for each individual building component, the global warming potential is illustrated in terms of several stages of building life-cycle. In this example, the Plywood Wall is again depicted as being more environmentally friendly, especially in the manufacturing stage of the lifecycle.

From the two examples evaluated in BEES and IE, the same environmental impacts could be shown in different ways. This may help users determine which tool they prefer to use.

Comparative Tool Analyses of Assemblies

The analysis based on EcoCalculator is the assembly-level methodology. The details of entire assemblies are built in the EcoCalculator spreadsheet chosen by users. Once the building location and type are decided, the components of the building enclosure are also determined. In BEES, the materials closest to typical building enclosure products are selected in order to directly compare the analysis results between BEES and EcoCalculator. The details of products and analysis results are shown in Tables 3 and 4. In Table 4, the results calculated with BEES and EcoCalculator are compared with a degree of interpretation in selecting materials within these two LCA tools. Although these two tools are built on the same database (U.S. LCI), they emphasize different materials. The characters of various components are selected and integrated inside of these tools. Therefore, the global warming potential results of wall assemblies are similar, but not exactly the same.

Table 3: Parameters in the case studies

Parameters	BEES	EcoCalculator
Area (ft^2)	1	
Building Life (yr)	50	
Environmental Impact	Global Warming Potential (GWP)	
Weights between different impact	equal weight	-
Transportation Distance (miles)	0	

Table 4: Comparative analysis of global warming potential with BEES and EcoCalculator

	BEES		EcoCalculator	
	Materials	GWP (gCO_2/ft^2)	Materials	GWP (gCO_2/ft^2)
Assembly 1	Generic Vinyl Cladding	1523	Vinyl Cladding	
	Generic Plywood Sheathing	377	Wood Structural Panel Sheathing	
	Anonymous R-19 Product	240	R-19 Cavity Insulation	
	Generic Gypsum Board	1916	Gypsum Board	
	Generic Latex Paint	101	Latex Paint	
		4157		3790
Assembly 2	Generic Brick & Mortar	3499	Brick Cladding	
	Generic Plywood Sheathing	377	Wood Structural Panel Sheathing	
	Anonymous R-19 Product	240	R-19 Cavity Insulation	
	Generic Gypsum Board	1916	Gypsum Board	
	Generic Latex Paint	101	Latex Paint	
		6133		5580
Assembly 3	Generic Stucco	1147	Stucco Cladding	
	Generic Plywood Sheathing	377	Wood Structural Panel Sheathing	
	Anonymous R-19 Product	240	R-19 Cavity Insulation	
	Generic Gypsum Board	1916	Gypsum Board	
	Generic Latex Paint	101	Latex Paint	
		3781		4630

DISCUSSION

The LCA tools that were reviewed were developed by three different organizations, resulting in four different tools, each with their own strengths and weaknesses. Table 5 is a brief summary of important properties for different LCA tools.

Table 5: The summary of properties for reviewed LCA tools

LCA Tools	SimaPro	BEES	ATHENA EcoCalculator	ATHENA Impact Estimator
Development organization	PRé Consultants (Netherlands)	EPA (US)	ATHENA (Canada)	ATHENA (Canada)
Analysis level	Variable	Product	Assembly	Building
Program complexity	high	low	low	medium
Model flexibility	high	low	low	medium
Detail coverage	high	low	low	medium
Process contribution analysis	Y	N	N	Y
Energy consumption	Y	Y	N	N
Environmental impact	Y	Y	Y	Y
Economic costs	Y	Y	N	Y
Overall performance	Y	Y	N	N

CONCLUSIONS

Life-cycle assessment is a comprehensive evaluation of building performance over its entire lifespan. There are many LCA tools developed for different fields of application. This study covered four LCA tools for building analyses, and discussed their applications. This paper started from the discussion of model constructions inside these tools, followed by case studies to compare different tools based on similar analysis conditions.

For the model construction, these four tools have different levels of flexibility and detail. Although SimaPro is the most complicated LCA tool reviewed in this study, it has the flexibility required to deal with complex building models. If a user wants to work on details of every process, SimaPro will also be the best choice. However, it will also take some time to learn to build models in SimaPro. If the users are interested in a more general analysis, they can turn to BEES and Athena EcoCalculator, which will significantly save time in the model set-up stage. SimaPro, which has the most powerful calculation engine, offers dozens of impact assessments to evaluate the performance of different products.

In terms of performance, analysis of environmental impacts is covered by all the tools in this study. Users could select appropriate tools for particular analysis required in their projects. Compared to environmental impacts assessment, energy consumption analyses can be only performed by SimaPro, BEES, and IE. To pursue an integrated analysis of buildings, overall performance is produced by BEES, which combines environmental performance and economic performance into a uniform scale of evaluation.

LCA is an analytical method to evaluate a product or system through all stages of its life cycle. Given the fact that different projects have various objectives of analysis, builders, architects, and engineers, should define the expected results and details of interest for their projects before starting life-cycle analyses in order to choose the right tool. Time and money limitations could also be influential factors in the selection of appropriate LCA tools.

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