INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
Vol. 12 No. 4 (2021) 20-34

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet
ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Environmental Value Engineering (EVE) Assessment: A Case Study of Comparing Curtain Wall System Alternatives

Simon Adamtey[1]

[1]Construction Management Department, College of Architecture and Environmental Design, Kent State University, Kent, Ohio, USA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2021.12.04.003
Received 01 January 2020; Accepted 20 December 2021; Available online 29 December 2021

Abstract: The need to explore environmentally friendly materials to avoid the depletion of the non-renewable resources is very significant. Humans have been heavily dependent on non-renewable resources since the industrial revolution. This has led to environmental impacts such as increase in CO2 in the atmosphere and global warming, which is arguably one of the major problems we are facing today. Faced with the possible shortages of natural resources, pollution, population overgrowth, and concern for protecting the environment, human beings are coming to realize that new concepts are needed to analyze the interdependent parts of the built environment. Considering the present need for optimal use of our resources, as opposed to maximizing, there is an increasing shift of focus to system evaluation methodologies that can be used to evaluate the environmental impact of a product or system. It is with this ever-increasing need for products that are not only functional and cost-effective, but also environmental friendly, that Environmental Value Engineering (EVE) assessment is gaining popularity. This paper explores the application of the EVE methodology through a case study of comparing the environmental impact of the C.T.W. Series 3 Wood Hybrid Curtain Wall system and the Kawneer 1600 Wall System. The EVE methodology, which is an environmental life cycle assessment method, was used to compare the inputs of the environment, fuel energy, goods, and services in terms of emergy for both systems.

Keywords: Emergy, environmental value engineering, transformity, non-renewable, alternatives

1. Introduction

Humanity has been heavily dependent on non-renewable resources since the industrial revolution. Non-renewable resources are finite and we are using these resources faster than the earth can re-grow them. Some of these resources require millions of years to be replenished. Depletion of resources can potentially end the human race. A classic example is the Easter Island discovered in 1722, whose inhabitants exploited their resources to the extreme, to their own extinction [1].

Perhaps, the most well-known impact of using non-renewable energy sources is the emission of greenhouse gases, in particular CO2 and methane, which contribute to climate change. The Intergovernmental Panel on Climate Change (IPCC) concluded that there is greater than 90 percent likelihood that people are causing global warming [2]. According to a report by the National Research Council, there is more CO2 in the atmosphere than at any time in the last 800,000 years [3]. The increase in CO2 levels is largely linked to emissions from fossil fuel combustion. Land use, air pollution, and deforestation also play a major role. The current concern is to reduce further human impact on the environment and to find ways to adapt to the change that has already occurred over the past several decades.

*Corresponding author: sadamtey@kent.edu

Environmentally friendly materials and methods are gaining much more popularity in the construction industry. Consumer interest in environmental issues has been gaining ground steadily and according to the Office of Energy and Environmental Industries (OEEI), the global market for environmental technologies is approximately $782 billion [4]. This interest is driving manufacturers and designers to explore options for green products. Using green products responds to this growing market demand for organic, nontoxic, energy-efficient, and earth-friendly products. Building and construction activities worldwide consume three billion tons of raw materials each year or 40 percent of total global use [5]. Using green building materials and products promote conservation of the dwindling non-renewable resources internationally. In addition, integrating green building materials into building projects can help reduce the environmental impacts associated with the extraction, transportation, processing, fabrication, installation, re-use, recycling, and disposal of these building materials.

Often, however, the question is not so much whether a greener, more efficient solution exists, but how to identify it and how to implement it. Many technologies have been developed to assess the environmental impact of materials, products and systems. Some of these are life cycle cost analysis (LCA), carbon foot print and cost-benefit analysis (CBA). The need to responsibly manage energy and environmental resources calls for the use of evaluation tools to compare these competing alternatives with a view of adopting the most environmental-friendly choice. Traditional LCA and CBA use money. Odum [6] explained that money cannot be used directly to measure environmental contributions to the public good since money is only paid to people for their services, not to the environmental service generating resources. The essence is to have a system evaluation methodology that can be used to compare environmental impact of competing alternatives and create a baseline for decision-making. It is with this ever-increasing need for products that are not only functional and cost-effective, but also environmental friendly, that environmental life cycle assessment is gaining popularity.

The intent of this study is to explore the application of Environmental Value Engineering (EVE) methodology through a case study of comparing the environmental impact of CTW Series 3 wood hybrid curtain wall system and the Kawneer 1600 wall system. The EVE methodology, which is an environmental life cycle assessment method, was used to compare the inputs of the environment, fuel energy, goods, and services in terms of emergy for both systems.

2. Environmental Value Engineering

Environmental Value Engineering is an environmental life cycle analysis methodology that evaluates the environmental impact and contribution of built alternatives in terms of solar e*mergy* through ten phases in the life cycle of a project. EVE is an alternative that can enable one to select alternatives that minimize environmental impact towards a sustainable society [7].

Environmental life cycle assessment is a tool used to systematically evaluate the environmental impact of a system. The concept of life cycle assessment is to evaluate the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth ("cradle to grave") [8]. Environmental Value Engineering is an environmental life cycle analysis methodology.

Dr. Wilfred H. Roudebush [8] developed the EVE methodology to account for the environmental role of built environmental alternatives. This life cycle analysis evaluates the environmental contribution and impact of built environmental alternatives in units of solar *emergy* over a complete built environment alternatives life cycle. Life cycle was defined to include all phases that a built environment alternative goes through, from natural resource formation through final disposal. Since production and consumption processes, which take place during all phases of a built environment alternative's life cycle use energy of differing quality or type, *emergy* was selected as the basic unit of quantification because it is energy of differing types converted into units of one type of energy [8]. A life cycle analysis of materials is available in the American Institute of Architect's Environmental Resource Guide. This methodology differs from EVE in that it has limited life cycle phases and does not account for inputs of environment, goods, and services [9].

2.1 Emergy Defined

Emergy is the unit of quantification utilized in EVE because it accounts for all the inputs of the environment, fuel energy, goods, and services. *Emergy*, a measure of real wealth, is defined as the sum of the available energy of one kind previously required directly or indirectly through input pathways to make a product or service [9]. Roudebush [10] defined *emergy* as all the available energy that was used in the work of making a product, including environmental impacts relating to inputs of environment, fuel energy, goods, and services (labor). The unit of *emergy* is the *Solar Emergy Joule* or *Solar Emjoules* (SEJ) to distinguish it from the regular Joule (J) and to point out a different quality assessment based on a donor side point of view [11].

2.2 The Ten Phases of Environmental Value Engineering

There are ten life cycle phases in EVE. These phases are natural resource formation, natural resource exploration and extraction, material production, design, component production, construction (assembly), use, demolition, natural resource recycling, and disposal. The 10 phases of EVE, in Table 1 below, are based on different production and consumption processes taking place within each phase. These production and consumption processes have distinct categorical environmental impact input requirements of environment (E), fuel energy (F), goods (G), and services (S) [12].

Table 1 - Ten phases of EVE

PHASE A	Natural resource formation
PHASE B	Natural resource exploration & extraction
PHASE C	Material production
PHASE D	Design
PHASE E	Component production
PHASE F	Construction (assembly)
PHASE G	Use
PHASE H	Demolition
PHASE I	Natural resource recycling (reuse)
PHASE J	Disposal

(Roudebush, 1992)

Consumption of minerals and energy begins with the conception of a built environment alternative and continues beyond its use phase. Traditional evaluation uses money. Since money goes only to pay for human services, it is not suitable for environmental value engineering. Embodied energy could not be used either because it accounts only for fuel energy and does not include environmental, goods, or services input sources (Roudebush, 1992). Construction methods include all alternatives that consume environment (E), fuel energy (F), goods (G), and services (S) inputs. This is expressed in the energy systems diagram shown in Figure 1 below.

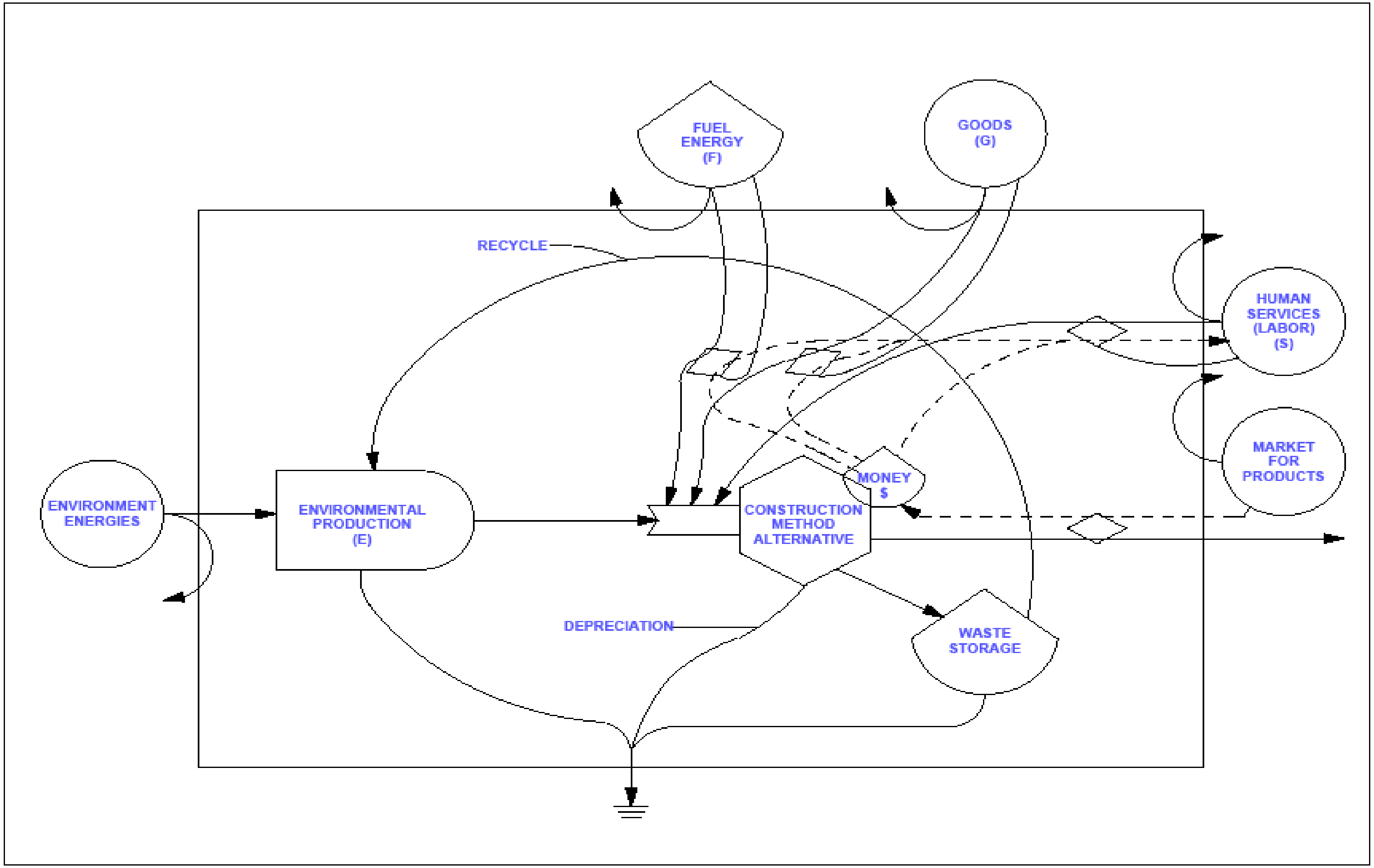

Fig. 1 - Energy systems diagram (Roudebush, 1997)

Table 2 - Environmental value engineering transformities[1]

Material	Unit	Transformities[2]
Aluminum ingots	(g)	1.60E+10
Asphalt	(J)	3.47E+05
Asphalt Concrete [3]	(g)	1.78E+09
Cement	(g)	3.30E+10
Clay	(g)	1.71E+09
Coal	(J)	3.98E+04
Concrete	(g)	9.99E+08
Copper	(g)	6.80E+10
Electricity	(J)	1.59E+05
Iron	(g)	1.80E+09
Limestone	(g)	1.62E+06
Machinery	(g)	6.70E+09
Natural gas	(J)	4.80E+04
Oil	(J)	5.30E+04
Petroleum product	(J)	6.60E+04
Plastic	(g)	3.20E+09
Polymers	(g)	3.20E+09
Rubber	(g)	4.30E+09
Soda Ash	(g)	1.62E+06
Service, labor[4]	($)	1.10E+12
Steel	(g)	1.80E+09
Stone, mined	(g)	1.00E+09
Stone, natural state	(g)	8.50E+08
Topsoil	(g)	1.71E+09
Water	(g)	7.28E+04
Wood	(J)	3.49E+04

[1]*Emergy Database* [12]*, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida.*
[2]*Transformity units are SEJ/J, SEJ/gram, SEJ/gal, SEJ/ lbs., or SEJ/US $.*
[3]*Transformity for the asphalt concrete pavement system from Roudebush (1997).*
[4]*Units in 2011 U.S. dollars (1998 figures adjusted for inflation).*

3.0 The alternatives: The C.T.W. Series 3 Wood Hybrid Curtain Wall System and The Kawneer 1600 Wall System

3.1 The C.T.W. Series 3 Wood Hybrid Curtain Wall

C.T.W. Engineering Glazing Systems manufactures the Series 3 Hybrid Wood and Aluminum Curtain Wall System. C.T.W. Engineered Glazing Systems is committed to delivering sustainable systems for use with today's modern methods of construction. The hybrid series 3 curtain walls is a high performance well drained stick system that achieves very high thermal insulation values. Comprising the insulation benefits of wood on the inside and aluminum on the outside, the curtain wall incorporates hybrid windows and doors specially designed for the system.

The Series 3 Wood and Aluminum curtain walls are constructed using vertical mullions with face fixed horizontal transoms on both the aluminum and the wood profiles as shown in Figure 2. The walls are tested in accordance with American Architectural Manufacturers Association (AAMA) and curtain wall standard. It is applicable for low to high rise buildings and suitable for high span applications [13].

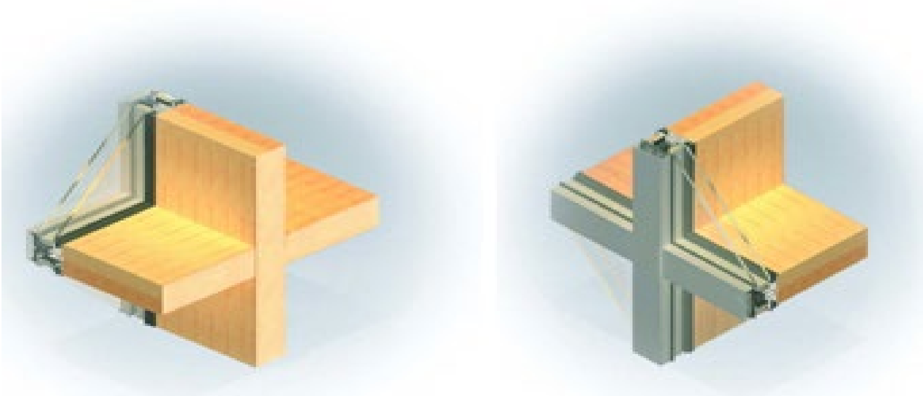

Fig. 2 - C.T.W. series 3 wood hybrid wall system (C.T.W., 2017)

3.2 The Kawneer 1600 Wall System

The Kawneer 1600 Wall System is manufactured by Kawneer Company, Incorporated. The Kawneer 1600 wall system comprises of a glazed aluminum wall system with aluminum mullions as shown in Figure 3. It is pressure glazed wall system for low-to-mid-rise applications and designed to be used independently or as an integrated system to provide visual impact for almost any type of building. There are two main types:

- 1600 Wall System®1: which is an outside glazed, captured curtain wall
- 1600 Wall System®2: this is a Structural Silicone Glazed (SSG) curtain wall.

The 1600 Wall System®1 was selected for this research project. The Kawneer1600 Wall System®1 has a 2.5" (63.5 cm) sight line. The system meets current codes requiring protection of openings in wind borne debris regions [14].

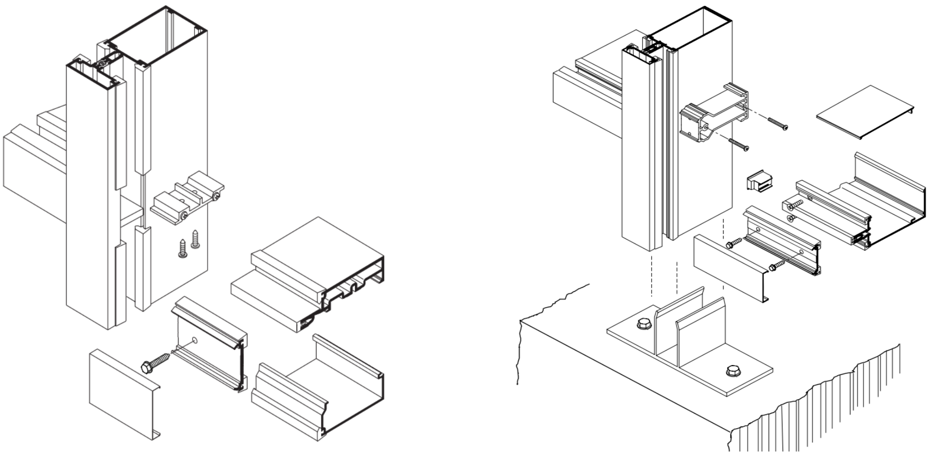

Fig. 3 - Kawneer 1600 wall system [14]

Methodology

To compare the environmental impact of both the C.T.W. Series 3 Wood Hybrid Curtain Wall System and the Kawneer 1600 Wall System, EVE was used to evaluate both alternatives. Alternative A was the C.T.W. Series 3 Wood Hybrid Curtain Wall System and alternative B was the Kawneer 1600 Wall System. Environmental Value Engineering *emergy* analysis tables were used to tabulate the *emergy* inputs required by these two window system alternatives through all 10 environmental value engineering life cycle phases. The *emergy* data was then input into aggregated *emergy* input source data table for comparison purposes.

4.1 Design Description of Alternatives

For equal comparison, a height of 25 feet and width of 25 feet was used for both wall systems. The design wind load for both systems was 21 pounds per square feet. The use phase for each alternative was set at 100 years.

The following assumptions were made for this research:

1. The rubber gaskets on both window systems are the same.
2. The glazing on both systems is the same.
3. The inputs for both systems at the design phase are the same and therefore no calculations are included.
4. There is no significant difference in the inputs at the component production phase.
5. There is no calculation for recycling phase. Inputs are assumed to be the same for both alternatives.
6. There is no disposal because it is assumed that all materials will be recycled.
7. The equipment used will not be recycled at the end of its useful life.

The C.T.W. Series 3 Wood Hybrid Curtain Wall System consists of a laminated oak mullion and aluminum cover. The mullion has an area of 2 inches x 8 inches. The mullion is replaced every 50 years. The sequencing of this alternative involves new construction at age 50 after demolition to last the 100-year use phase.

The Kawneers1600 Curtain Wall consists of aluminum mullion and aluminum cover. The mullion has an area of 2 inches x 6 inches. This is replaced every 100 years. The sequencing of both alternatives involve demolition at 100 years.

4.2 Emergy Input Calculations

Emergy input calculation methods were applied to the assessment as follows:

1. Material mass quantity take-offs were conducted based on curtain wall descriptions and dimensions for initial environmental impact *emergy* of material transformity phases A-C for both alternatives.
2. Environmental value engineering *emergy* input tables were constructed for each phase of each curtain wall alternatives. An example of the construction phase (F) for the C.T.W. Series 3 Wood Hybrid Curtain Wall System is shown in Table 2.
3. Applicable *emergy* transformities were used to convert the various inputs to SEJ.

Table 2 - Construction phase EVE *emergy* input table

Note	Item	Raw Units G, J, $	Transformity SEJ/Unit	Solar Emergy SEJ
E	**Environment**			**NA**
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	**Fuel Energy**			**8.98×10^{14}**
F1	Equipment	1.36×10^{10} J	6.60×10^{4}	8.98×10^{14}
F2	Facilities	NA		
G	**Goods**			**5.72×10^{13}**
G1	Equipment	8.54×10^{3} g	6.70×10^{9}	5.72×10^{13}
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	**Services**			**4.82×10^{15}**
S1	Labor	$2.41x10^3 → $\$2.41 \times 10^{3}$	2.00×10^{12}	4.82×10^{15}

Findings

Table 3 presents the findings from the EVE analysis and calculations in Appendix A.

Table 3 - The C.T.W. series 3 wood hybrid versus Kawneer 1600 wall systems SEJs

Alternatives		Inputs in SEJs				Total SEJs
		Environment	Fuel Energy	Goods	Services	
A	C.T.W.	3.64×10^{18}	3.64×10^{18}	3.64×10^{18}	3.64×10^{18}	$\mathbf{1.46 \times 10^{19}}$
B	Kawneer	7.72×10^{14}	1.75×10^{15}	8.52×10^{14}	6.11×10^{15}	$\mathbf{9.49 \times 10^{15}}$

From this case study EVE analysis of the window systems, it can be concluded based on the results that the C.T.W. Series 3 Wood Hybrid Curtain Wall System accounts for 1.46x1019 SEJs while the Kawneer 1600 Wall System accounts for 9.49x1015 SEJs. The C.T.W. Series 3 Wood Hybrid Curtain Wall System requires 1.46x1019 SEJs more than the Kawneer 1600 Wall System. Therefore, the Kawneer 1600 Wall System alternative is more environmentally friendly.

6.0 Conclusions

The need to responsibly manage energy and environmental resources calls for the use of evaluation tools to compare these competing alternatives with a view of adopting the most environmental-friendly choice. Assessment of environmental impact should be considered from ‘cradle to grave’ and that is why environmental life cycle assessment methodology such as EVE is gaining popularity.

Environmental Value Engineering evaluates the environmental contribution and impact of built environmental alternatives in units of *emergy*. By utilizing this methodology, a well-informed decision can be made when deciding on building component or material alternatives that are green or have less environmental impact. It is important to note that there are different methodologies for assessing impact and may yield different results. Environmental Value Engineering is another tool that must be considered to account for the inputs of environment, fuel energy, goods, and services of the alternatives competing for similar resources

References

[1] S. Ross and M. Dru, Green Building Materials: A Guide to Product Selection and Specification, Cambridge: Cambridge University Press, 1999.

[2] IPCC, "IPCC Fourth Assessment Report: Climate Change 2007.," Intergovernmental Panel on Climate Change, Washongton DC, 2007.

[3] National Research Council, "Adapting to the Impacts of Climate Change," The National Academis Press, Washiington, DC., 2010.

[4] OEEI, "Industry Facts," Government Printing Office, Washington DC, 2012.

[5] D. Roodman and N. Lenssen, "A Building Revolution: How Ecology and Health Concerns are Transforming Construction," Worldwatch Institute, Washington DC, 1995.

[6] H. Odum, "Self-organization, transformity, and information.," American Assocaition for the Advancement of Science , pp. 1132-1139, 1988.

[7] L. Onsarigo, A. Atalah and W. Roudebush, "An Introduction to Environmental Value Engineering (EVE) and the EVE Assessment of Horizontal Directional Drilling (HDD) versus Open-Cut Construction," in ASCE Pipeline Conference, Portland, 2014.

[8] W. Roudebush, "Environmental Value Engineering (EVE): A system for Analyzing the Environmental Impact of Built Environment Alternatives.," University of Florida, Gainesville, 1992.

[9] H. Odum, "Energy Evaluation of an OTEC Electrical Power System," Energy, pp. 389-393, 2000.

[10] W. H. Roudebush, "Environmental Value Engineering: An Environmental Life Cycle Assessment Methodology for Comparing Built Environment Alternatives.," in American Society for Engineering Education Annual Conference, Nashville, 2003.

[11] H. Odum and E. Odum, "The Prosperous Way Down," Energy, pp. 21-32, 2006.

[12] The Emergy Database, "Transformities," 2010. [Online]. Available: http://emergydatabase.org/transformities-view/all. [Accessed 11 July 2017].

[13] C.T.W. Engineering Glazing Systems, "C.T.W. Engineering Glazing Systems," 2017. [Online]. Available: http://www.ctwindowsinc.com/products-ctwindows-hybrid-aluminum-wood-curtain-wall-series-manufacturer.html#Series 3: HYBRID. [Accessed 11 July 2017].

[14] Kawneer, "Kawneer Company," 2017. [Online]. Available: http://www.kawneer.com/kawneer/north_america/en/product.asp?cat_id=1992&prod_id=1801&desc=hurricane-resistant-curved-curtain-wall-systems. [Accessed 12 July 2017].
[15] H. Odum, "Emergy Evaluation," in International Workshop on Advances in Energy Studies: Energy Flows in Ecology and Economy, Porto Venere, 1998.
[16] W. Roudebush, "Environmental Value Engineering (EVE): Environmental Life Cycle Assessment of Concrete and Asphalt Highway Pavement Systems," Portland Cement Association, Portland, 1997.

8. Appendix A: EVE Calculations

The C.T.W. Series 3 Wood Hybrid Curtain Wall System

Material Transformity Phases A-C emergy Input Calculations

Materials

Wood transformity = $3.49x10^4$ sej/j
Aluminum transformity = $1.60x10^{10}$ sej/g
Weight of wood = 3.46 lbs/ft
Weight of aluminum = 0.68 lbs/ft

Wood Quantity

Length = 25 feet x 5 = 125 feet
Energy = (125 ft) (3.46 lbs/ft) (453.59 g/lbs) ($1.59x10^4$ J/g) = $3.2x10^9$ j

Aluminum Quantity

Length = 25 feet x 5 = 125 feet
Mass = (125 ft) (0.68 lbs/ft) (453.59 g/lbs) = $3.86x10^4$ g

E. ENVIRONMENT

Wood

Environment input transformity portion = 25% (Est.)
($3.49x10^4$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^9$ j) = $2.79x10^{13}$ sej

Aluminum

Environment input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g
($4.0x10^9$ sej/g) ($3.86x10^4$ g) = $1.54x10^{14}$ sej

Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

F. FUEL

Wood

Fuel energy input transformity portion = 25% (Est.)
($3.49x10^4$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^9$ j) = $2.79x10^{13}$ sej

Aluminum

Fuel energy input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g
($4.0x10^9$ sej/g) ($3.86x10^4$ g) = $1.54x10^{14}$ sej

Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

G. GOODS

Wood

Goods input transformity portion =25 % (Est.)
($3.49x10^4$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^9$ j) = $2.79x10^{13}$ sej

Aluminum

Goods input transformity portion = 25% (Est.)
(1.60E10 sej/g) (0.25) = 4.0E9 sej/g
(4.0E9 sej/g) (3.86E4 g) = 1.54E14 sej

Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

S. SERVICES

Wood

Services input transformity portion = % (Est.)
($3.49x10^4$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^9$ j) = $2.79x10^{13}$ sej

Aluminum

Services input transformity portion = 25% (Est.)

(1.60E10 sej/g) (0.25) = 4.0E9 sej/g

(4.0E9 sej/g) (3.86E4 g) = 1.54E14 sej

Total Environment solar EMERGY input = **1.82×10^{18} sej**

Construction Phase F emergy Input Calculations

Area of curtain wall = 25 ft x 25 ft = 625 ft^2

Workers = 4

Equipment = JLG articulating boom lift

Productivity = 160 sf/day (8 hrs) = 20 ft^2/hr (From RS Means 2010)

E. ENVIRONMENT

N/A

F. FUEL ENERGY

F1. Equipment

F1.JLG articulating boom lift (740AJ) (From http://www.jlg.com)

Fuel consumption = 3.5 gal/hr (Est.)

Use = 32 hrs

(32 hr) (3.5 gal/hrs) = 112 gal

[(112 gal) / (42 gal/BBL)] (6.28E9 J/BBL) = **1.67E10 J**

G. GOODS

G1. Equipment

G1. F1.JLG articulating boom lift (740AJ)

Weight = 36,200 lbs

Useful life = 50,000 hrs

Use = 32 hrs

[(32 hrs) / (50,000 hrs)] (36,200 lb) (453.6 g/lb) = **1.05E4 g**

S. SERVICES

S1.1 Two glaziers (From RS Means 2010)

Labor hrs = 32 hrs

Labor salary = \$25.35/hr

Labor = (32 hrs) (\$25.35/hr) x 2 = \$1,622.4

S1.2 Two steel/wood workers (From RS Means 2010)

Labor hrs = 32 hrs

Labor salary = \$20.98

Labor = (32 hrs) (\$20.98/hr) x 2 = \$1,342.72

Total S1 labor = **\$2.97E3**

Use Phase G emergy Input Calculations

[Removal of original window at year 50 and new construction at year 50**]**

Materials

Wood transformity = 3.49×10^4 sej/j

Aluminum transformity = 1.60×10^{10} sej/g

Weight of wood = 3.46 lbs/ft

Weight of aluminum = 0.68 lbs/ft

Wood Quantity

Length = 25 feet x 5 = 125 feet

Energy = (125 ft) (3.46 lbs/ft) (453.59 g/lbs) (1.59×10^4 J/g) = 3.12×10^9 j

Aluminum Quantity

Length = 25 feet x 5 = 125 feet

Mass = (125 ft) (0.68 lbs/ft) (453.59 g/lbs) = 3.86×10^4 g

Area of curtain wall = 25 ft x 25 ft = 625 ft^2

E. ENVIRONMENT

E6. Materials

Wood

Environment input transformity portion = 25% (Est.)

(3.49×10^4 sej/j) (0.25) = 8725 sej/j

(8725 sej/j) (3.2×10^9 j) = 2.79×10^{13} sej

Aluminum

Environment input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^{9}$ sej/g
($4.0x10^{9}$ sej/g) ($3.86x10^{4}$ g) = $1.54x10^{14}$ sej
Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

F. FUEL ENERGY

DEMOLITION

F1. Equipment

F1. Hitachi demolisher with attachment (ZAXIS240LC) (From www.**hitachi**.com)
Fuel consumption = 4 gal/hr
Demolition rate = 450 ft^2/hr
Use = 625 ft^2/450 ft^2/hr =1.39 hr
(1.39 hr) (4 gal/hr) = 5.56 gal
[(5.56 gal) / (42 gal/BBL)] ($6.28x10^{9}$ J/BBL) = $8.31x10^{9}$ J

F1. Hitachi Dump truck (ZX850-a)
Truck bucket capacity = 124 ft^3
Fuel consumption = 5 gal/hr
Demolisher rate = 450 ft^3/hr

Loading time = (124 ft^3 /450 ft^3) x60 mins = 16.53 mins
Dump + traveling time = [(2 trips x15 miles x 60 mins/hr)/30 mi/hr] + 5 min/load = 65 mins
Cycle time = 16.53 + 65 = 81.53 mins
Number of trucks = 81.53/16.53 = 5
Use = 625 ft^2/450 ft^2/hr =1.39 hr
(1.39 hr) (5 gal/hr) = 6.95gal
(5) [(6.95 gal) / (42 gal/BBL)] ($6.28x10^{9}$ J/BBL) = $5.20x10^{9}$J

NEW CONSTRUCTION

F1. Equipment
F1.JLG articulating boom lift (740AJ)
Fuel consumption = 3.5 gal/hr (Est.)
Use = 32 hrs
(32 hr) (3.5 gal/hrs) = 112 gal
[(112 gal) / (42 gal/BBL)] (6.28E9 J/BBL) = $1.67x10^{10}$ J
Total F1 Equipment **= $3.02x10^{10}$J**

F3. Materials

Wood
Environment input transformity portion = 25% (Est.)
($3.49x10^{4}$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^{9}$ j) = $2.79x10^{13}$ sej

Aluminum
Environment input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^{9}$ sej/g
($4.0x10^{9}$ sej/g) ($3.86x10^{4}$ g) = $1.54x10^{14}$ sej
Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

G. GOODS

DEMOLITION

G1. Equipment
G1. Hitachi demolisher with attachment (ZAXIS240LC)
Weight = 45,000 lb
Useful life = 50,000 hrs
Use = 625ft^2/450 ft^2/hr =1.39 hr
[(1.39 hrs) / (50,000 hrs)] (45,000 lb) (453.6 gal/lb) = 567.45 g

G1. Hitachi Dump truck (ZX850-a)
Weight = 50,000 lb
Useful life = 50, 000 hrs
Use = 625 ft^2/450 ft^2/hr =1.39 hr

(5) [(1.39 hrs) / (50,000 hrs)] (50,000 lb) (453.6 gal/lb) = $3.15x10^3$ g

NEW CONSTRUCTION

G1. Equipment
G1. F1.JLG articulating boom lift (740AJ)
Weight = 36,200 lbs
Useful life = 50,000 hrs
Use = 32 hrs
[(32 hrs) / (50,000 hrs)] (36,200 lb) (453.6 gal/lb) = $1.05x10^4$ g
Total G1 **= $1.42x10^4$ g**

G3. Materials

Wood

Environment input transformity portion = 25% (Est.)
($3.49x10^4$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^9$ j) = $2.79x10^{13}$ sej

Aluminum

Environment input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g
($4.0x10^9$ sej/g) ($3.86x10^4$ g) = $1.54x10^{14}$ sej

Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

S. SERVICES

DEMOLITION

S1. Labor
Demolition rate = 450 ft^2/hr
Demolition duration = 625 ft^2/450 ft^2/hr =1.39 hr
<u>Crew</u>
Demolisher driver = $ 28/hr = 28x1.39 = $ 38.92
5 dump truck drivers = $ 28/hr = 5x28x1.39 = $ 194.60
2 laborers = $ 20/hr = 2x20x1.39 = $ 55.6
Total labor cost = $ 289.12

NEW CONSTRUCTION

S1.1 Two glaziers
Labor hrs = 32 hrs
Labor salary = $ 25.35/hr
Labor = (32 hrs) ($ 25.35/hr) x 2 = $ 1,622.4

S1.2 Two steel/wood workers
Labor hrs = 32 hrs
Labor salary = $ 20.98
Labor = (32 hrs) ($ 20.98/hr) x 2 = $ 1,342.72
Total S1 labor = **$ $3.25x10^3$**

S2. Materials

Wood

Environment input transformity portion = 25% (Est.)
($3.49x10^4$ sej/j) (0.25) = 8725 sej/j
(8725 sej/j) ($3.2x10^9$ j) = $2.79x10^{13}$ sej

Aluminum

Environment input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g
($4.0x10^9$ sej/g) ($3.86x10^4$ g) = $1.54x10^{14}$ sej

Total Environment solar EMERGY input = **$1.82x10^{18}$ sej**

_Demolition H emergy Input Calculation

E. ENVIRONMENT

NA

F. FUEL ENERGY

DEMOLITION

F1. Equipment

F1. Hitachi demolisher with attachment (ZAXIS240LC)
Fuel consumption = 4 gal/hr
Demolition rate = 350 ft^2/hr
Use = 625 ft^2/350 ft^2/hr =1.79 hr
(1.79 hr) (4 gal/hr) = 7.16 gal
[(7.16 gal) / (42 gal/BBL)] (6.28E9 J/BBL) = $1.07x10^9$ J

F1. Hitachi Dump truck (ZX850-a)
Truck bucket capacity = 124 ft^3
Fuel consumption = 5 gal/hr
Demolisher rate = 350 ft^3/hr

Loading time = (124 ft^3 /350 ft^3) x60 mins = 21.25 mins
Dump + traveling time = [(2x15x60)/30] + 5 = 65 mins
Cycle time = 21.25 + 65 = 86.25mins
Number of trucks = 86.25/21.25 = 4
Use = 625 ft^2/350 ft^2/hr =1.79 hr
(1.79 hr) (5 gal/hr) = 8.95 gal
(4) [(8.95 gal) / (42 gal/BBL)] ($6.28x10^9$ J/BBL) = $5.35x10^9$ J
Total F1 **= $6.42x10^9$ J**

G. GOODS

DEMOLITION

G1. Equipment
G1. Hitachi demolisher with attachment (ZAXIS240LC)
Weight = 45,000 lb
Useful life = 50,000 hrs
Use = 625 ft^2/350 ft^2/hr =1.79 hr
[(1.79 hrs) / (50,000 hrs)] (45,000 lb) (453.6 gal/lb) = 730.75 g

G1. Hitachi Dump truck (ZX850-a)
Weight = 50,000 lb
Useful life = 50, 000 hrs
Use = 625 ft^2/350 ft^2/hr =1.79 hr
(4) [(1.79 hrs) / (50,000 hrs)] (50,000 lb) (453.6 gal/lb) = $3.25x10^3$ g
Total G1 **= $3.98x10^3$g**

S. SERVICES

DEMOLITION

S1. Labor
Demolition rate = 350 ft^2/hr
Demolition duration = 625 ft^2/350 ft^2/hr =1.79 hr
<u>Crew</u>
Demolisher driver = \$ 28/hr = 28x1.79 = \$ 50.12
4 dump truck drivers = \$ 28/hr = 4x28x1.79 = \$ 200.48
2 laborers = \$ 20/hr = 2x20x1.79 = \$ 71.6
Total labor cost = **\$ 322.20**

The Kawneer 1600 Wall System

Material Transformity Phases A-C EMERGY Input Calculations

Materials

Aluminum transformity = $1.60x10^{10}$ sej/g
Weight of aluminum = 3.4 lb/ft

Aluminum Quantity

Length = 25feet x 5 = 125 feet
Mass = (125ft) (3.4 lbs/ft) (453.59 g/lbs) = $1.93x10^5$ g

E. ENVIRONMENT

Aluminum

Environment input transformity portion = 25% (Est.)
($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g
($4.0x10^9$ sej/g) ($1.93x10^5$ g) = $7.72x10^{14}$ sej

Total Environment solar EMERGY input = **$7.72x10^{14}$ sej**

F. FUEL

Aluminum

Fuel energy input transformity portion = 25% (Est.)

($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g

($4.0x10^9$ sej/g) ($1.93x10^5$ g) = $7.72x10^{14}$ sej

Total Environment solar EMERGY input = **$7.72x10^{14}$ sej**

G. GOODS

Aluminum

Goods input transformity portion = 25% (Est.)

($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g

($4.0x10^9$ sej/g) ($1.93x10^5$ g) = $7.72x10^{14}$ sej

Total Environment solar EMERGY input = **$7.72x10^{14}$ sej**

S. SERVICES

Aluminum

Services input transformity portion = 25% (Est.)

($1.60x10^{10}$ sej/g) (0.25) = $4.0x10^9$ sej/g

($4.0x10^9$ sej/g) ($1.93x10^5$ g) = $7.72x10^{14}$ sej

Total Environment solar EMERGY input = **$7.72x10^{14}$ sej**

Construction Phase F EMERGY Input Calculations

Area of curtain wall = 25 ft x 25 ft = 625 ft^2

Workers = 4

Equipment = JLG articulating boom lift

Productivity = 190 sf/day (8hrs) = 24 ft^2/hr

E. ENVIRONMENT

NA

F. FUEL ENERGY

F1. Equipment

F1.JLG articulating boom lift (740AJ)

Fuel consumption = 3.5 gal/hr (Est.)

Use = 26 hrs

(26hr) (3.5 gal/hrs) = 91 gal

[(91 gal) / (42 gal/BBL)] ($6.28x10^9$ J/BBL) = **$1.36x10^{10}$ J**

G. GOODS

G1. Equipment

G1. F1.JLG articulating boom lift (740AJ)

Weight = 36,200 lbs

Useful life = 50,000 hrs

Use = 26 hrs

[(26hrs) / (50,000 hrs)] (36,200 lb) (453.6 gal/lb) = **$8.54x10^3$ g**

S. SERVICES

S1.1 Two glaziers

Labor hrs = 26 hrs

Labor salary = $ 25.35/hr

Labor = (26 hrs) ($ 25.35/hr) x 2 = $ 1,318.2

S1.2 Two steel workers

Labor hrs = 26 hrs

Labor salary = $ 20.98

Labor = (26 hrs) ($ 20.98/hr) x 2 = $ 1,090.96

Total S1 labor = **$ $2.41x10^3$**

Demolition H emergy Input Calculations

E. ENVIRONMENT

NA

F. FUEL ENERGY

DEMOLITION

F1. Equipment

F1. Hitachi demolisher with attachment (ZAXIS240LC)

Fuel consumption = 4 gal/hr

Demolition rate = 500 ft^2/hr
Use = 625 ft^2/500 ft^2/hr =1.25 hr
(1.25 hr) (4 gal/hr) = 5 gal
[(5 gal) / (42 gal/BBL)] (6.28x10^9 J/BBL) = 7.48x10^9J

F1. Hitachi Dump truck (ZX850-a)
Truck bucket capacity = 124 ft^3
Fuel consumption = 5 gal/hr
Demolisher rate = 500ft^3/hr

Loading time = (124 ft^3 /500 ft^3) x60 mins = 14.88 mins
Dump + traveling time = [(2 trips x15 mi x 60 min/hr)/30 mi/hr] + 5 min = 65 mins
Cycle time = 14.88 + 65 = 79.88 mins
Number of trucks = 79.88/14.88 = 5
Use = 625 ft^2/500 ft^2/hr =1.25 hr
(1.25 hr) (5 gal/hr) = 6.25 gal
(5) [(6.25 gal) / (42 gal/BBL)] (6.28x10^9 J/BBL) = 4.67x10^9 J
Total F1 **= 1.22x10^9 J**

G. GOODS

DEMOLITION

G1. Equipment
G1. Hitachi demolisher with attachment (ZAXIS240LC)
Weight = 45,000 lb
Useful life = 50,000 hrs
Use = 625 ft^2/500 ft^2/hr =1.25 hr
[(1.25 hrs) / (50,000 hrs)] (45,000 lb) (453.6 gal/lb) = 510.30 g

G1. Hitachi Dump truck (ZX850-a)
Weight = 50,000 lb
Useful life = 50, 000 hrs
Use = 625 ft^2/500 ft^2/hr =1.25 hr
(5) [(1.25 hrs) / (50,000 hrs)] (50,000 lb) (453.6 gal/lb) = 2.84x10^3 g
Total G1 **= 3.35x10^3 g**

S. SERVICES

DEMOLITION

S1. Labor
Demolition rate = 350 ft^2/hr
Demolition duration = 625 ft^2/500 ft^2/hr =1.25 hr
<u>Crew</u>
Demolisher driver = $ 28/hr = 28x1.25 = $ 35.00
5 dump truck drivers = $ 28/hr = 5x28x1.25 = $175.00
2 laborers = $ 20/hr = 2x20x1.25 = $ 50.00
Total labor cost = **$ 260.00**