Session #2506

Environmental Value Engineering: An environmental life cycle assessment methodology for comparing built environment alternatives.

Wilfred H. Roudebush, Ph.D., NCARB

College of Technology
Bowling Green State University
Bowling Green, Ohio 43403-0302
Office: (419) 372-8275
FAX (419) 372-6066
Email: wroudeb@bgnet.bgsu.edu

Overview

Purpose of the Paper

Engineering education should prepare graduates to properly consider the environmental impact of their decisions toward sustainable development. Built environment alternatives compete for inputs of environment, fuel energy, goods, and human services (labor). Current assessment methodologies for comparing built environment alternatives only consider money related to labor or embodied energy in terms of fuel energy. Environmental life cycle assessment methodologies are being developed that consider all inputs and related environmental impacts.

The purpose of this paper is to present Environmental Value Engineering as an environmental life cycle assessment methodology that applies the concept of EMERGY as an environmental decision making tool. Elements of the methodology are described, including EMERGY calculation procedures, and an application of the methodology that compares two built environment alternatives (exterior wall system alternatives for a building) is presented.

Educational use of the Environmental Value Engineering methodology will create an awareness of the environmental effects that decisions on built environment alternatives will have on the availability of competing inputs of environment, fuel energy, goods, and services (labor).

Alternative Environmental Assessment Methodologies

A life cycle analysis of materials is available in the American Institute of Architect's Environmental Resource Guide[1]. This methodology differs from Environmental Value Engineering in that it has limited life cycle phases and does not account for inputs of environment, goods, and services.

Decisions based on an environmental impact analysis may rely on an Environmental Impact Statement. An Environmental Impact Statement is an inventory, analysis, and evaluation of the effect of a planned built environment project on surrounding environmental quality as stipulated by the National Environmental Policy Act (NEPA)[6]. Decisions based on an Environmental Impact Statement are qualitative, whereas decisions based on Environmental Value Engineering are quantitative.

Defining Environmental Value Engineering

Built environment alternatives should be selected that minimize environmental impact toward a sustainable society. Environmental Value Engineering can be used to assess and compare the environmental impact of multiple built environment alternatives, in terms of EMERGY, through the following 10 life cycle phases of built environment alternatives: natural resource formation, natural resource exploration and extraction, material production, design, component production, construction, use, demolition, natural resource recycling, and disposal.

Key Words

Environmental Value Engineering, environmental life cycle assessment, environmental impact, EMERGY, EMERGY analysis, embodied energy, life cycle phases.

Explaining the EMERGY Concept

Environmental Value Engineering uses EMERGY, spelled with an "M", as a basis of quantification, instead of money or embodied energy. EMERGY is a scientific-based measure of wealth, that puts raw materials, commodities, goods, and services on a common basis, the energy of one type required to generate that item[2]. EMERGY is defined 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). EMERGY is expressed in standard units of energy called solar emjoules (SEJ). These inputs of EMERGY are represented in the energy systems diagram of Figure 1. All built environment alternatives compete for inputs indicated outside the energy systems diagram boundary. Money, indicated by dashed lines in Figure 1, circulates into the system to pay only for human services. Money is not paid to the environment, and money that is paid for labor cannot be used to evaluate benefits or losses to the environment.

The methodology may be used to assess the sustainability of single systems of a built environment alternative or to compare the sustainability of multiple built environment alternatives. The methodology essentially accounts for all inputs to a built environment alternative over a life cycle consisting of all phases that a built environment alternative goes through, from natural resource formation by the environment through final disposal. In other words, the assessment depicts EMERGY concentrations that occur during the life cycles of built environment alternatives. A built environment alternative uses the earth's renewable and nonrenewable resources throughout its life cycle.

Figure 1 is an energy systems diagram based on general systems modeling techniques developed by the late Dr. Howard T. Odum, a pioneer of ecology.

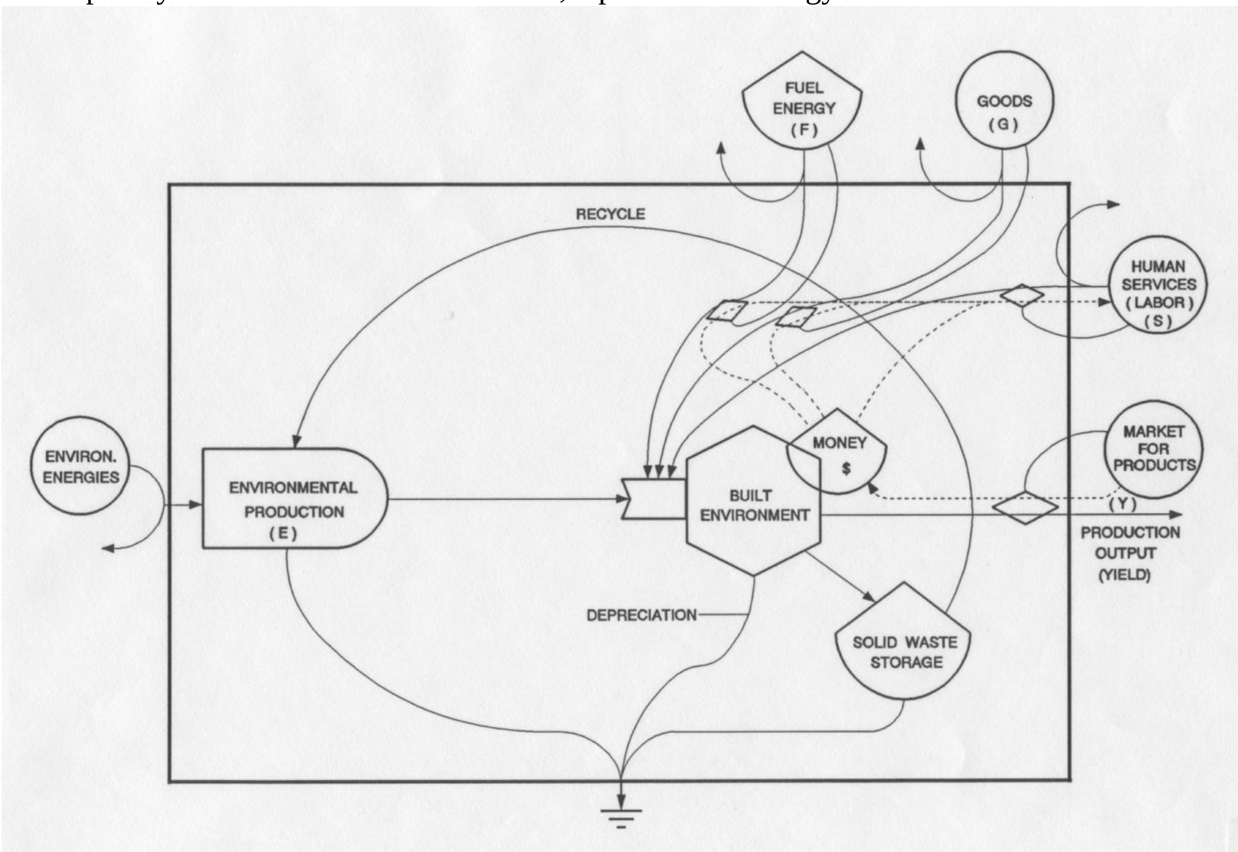

Figure 1. Energy Systems Diagram of Built Environment Alternative

Environmental value engineering evaluates the environmental contribution and impact of built environment alternatives in units of solar EMERGY during the alternative's life cycle. The sum of EMERGY contributions to each life cycle phase is added as an input to the next. Therefore, EMERGY accumulates from one life cycle phase to the next. "EMERGY is not only a measure of what went into a product, it is a measure of the useful contributions which can be expected from that product as an economy self organizes for maximum production[1]". Selection of built environment alternatives that contribute most to society while drawing the least, leads toward a sustainable society.

Describing the Environmental Value Engineering methodology

The components and structure of the Environmental Value Engineering methodology are imbedded in its very definition. The methodology quantifies, in EMERGY terms, four categories of inputs involved in the work of making (construction), using, and disposal of multiple built environment alternatives during 10 life cycle phases that are described later. The following aspects of environmental value engineering are presented: systems approach, inputs, life cycle phases, input tranformities, and EMERGY calculation procedures.

Systems Approach

A built environment system is composed of multiple subsystems. This paper presents the built environment system setting of a building and one of its subsystem components. A building subsystem, such as exterior walls, incorporates components that are still lower in the building systemic hierarchy. As Environmental Value Engineering is suited to compare EMERGY between two or more systems, the label "built environment system alternative" is appropriate. According to the Environmental Value Engineering methodology, EMERGY can be calculated for any or all parts of systems being compared. Determining and designating subsystems is one of the first steps in conducting an Environmental Value Engineering assessment of the built environment alternatives. Subsystem designations already exist for many built environment alternatives. For example, comparisons related to buildings can use UNIFORMAT subsystem designations. UNIFORMAT was developed jointly by the American Institute of Architects and the United States General Services Administration[7].

Inputs

The Environmental Value Engineering methodology is a unique approach to environmental life cycle assessment[4]. Inputs, in terms of EMERGY, of environment, fuel energy, goods, and services (labor) are accounted for during 10 life cycle phases.

Life Cycle Phases

The methodology incorporates the following 10 life cycle phases through which built environmental alternatives are to be assessed: A. natural resource formation, B. natural resource exploration and extraction, C. material production, D. design, E. component production, F. fabrication/construction, G. use, H. demolition, I. natural resource recycling, and J. disposal. The phases near the two extremes of the life cycle, in particular, indicate the all-encompassing nature of the methodology. For example, the natural resource formation phase is intended to account for the value of environmental inputs during the formation of resources on Earth.

Input Transformities

A unique feature of Environmental Value Engineering is the use of EMERGY as the measure of input quantification (EMERGY calculation methods will be described later). Traditional assessments use money or embodied energy to quantify inputs. Since money only goes to pay for human services, it is not suitable for Environmental Value Engineering. Embodied energy is not suitable either because it usually only accounts for fuel energy inputs. Embodied energy also ignores fuel energy quality and usually does not include inputs of environment (resources) and services (labor). Since the production and consumption processes, that 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 calculated into units of one type of energy. So as not to confuse EMERGY with energy, the word EMERGY is capitalized in this paper. Solar emjoules (SEJ) are units of solar EMERGY that are the basic unit of quantification used in Environmental Value

Engineering. According to Odum[3], solar EMERGY is the solar energy required directly and indirectly to make a product or service.

Table 1 provides solar transformities that were obtained from EMERGY analysis research data that is based on the scientific methods of the late Dr. Howard T. Odum and his associates at the University of Florida, Gainesville, Florida, and Roudebush[5].

TABLE 1. TRANSFORMITY LIST

Transformities (EMERGY conversions) for energies, resources, and commodities related to the built environment in terms of solar emjoules/Joule, solar emjoules/gram or solar emjoules/United States dollar. Environmental impacts are included in the respective transformity of each material.

Material	**Transformity**
(Refer to note 1 unless noted otherwise.)	
Aluminum ingots (g)	1.60E10
Asphalt (J)	3.47E5
Asphalt concrete (g)	1.78E9 (Refer to note 2)
Coal (J)	3.98E4
Concrete (g)	9.99E8 (Refer to note 2)
Copper (g)	6.80E10
Electricity (J)	1.59E5
Glass (g)	8.40E8
Grain (J)	6.80E4
Iron (g)	1.80E9
Machinery (g)	6.70E9
Natural gas (J)	4.80E4
Nitrogen fertilizer (J)	1.69E6
Oil (J)	5.30E4
Paper (J)	2.15E5
Petroleum product (J)	6.60E4
Plastic (g)	3.80E8
Rubber (g)	4.30E9
Service, labor (US $)	2.00E12 (Refer to note 3)
Steel (g)	1.80E9
Stone, mined (g)	1.00E9
Stone, natural state (g)	8.50E8
Topsoil (J)	6.30E4
Water, consumer (J)	6.66E5
Water, waste (J)	4.10E4
Wood (J)	3.49E4
Zinc Alloys (g)	6.80E10

Notes to Table 1:

1. Source: The late Dr. Howard T. Odum, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida.
2. Transformity calculations are given in Roudebush[5].
3. Units in 1990 United States dollars.

EMERGY Calculation Procedures

The end product of Environmental Value Engineering calculations is an aggregated EMERGY input table for each built environment alternative being compared. These tables summarize EMERGY input of each sub-system through the 10 life cycle phases of each built environment alternative that are first calculated in EMERGY input tables.

The procedures for making an EMERGY input table follow:

1. Make an EMERGY input table for each built environment alternative system and each life cycle phase with one line in the table for each environment, fuel energy, goods, and services EMERGY input source.
2. Number the lines to match calculation back-up sheets for data sources, references, calculations, and other details.
3. Put the input source in the item column.
4. In the second column of data put the raw data units for each item in grams, Joules, or U.S. dollars.
5. Put the appropriate solar transformity in the next column. Solar transformities (EMERGY conversions) for energies, resources, and commodities related to the built environment are provided in Table 1.
6. In the fourth column, multiply raw data units from column 2 by the solar transformity from column 3, thus obtaining solar EMERGY values in solar emjoules (SEJ).
7. Input the solar EMERGY values for each phase of each built environment alternative into the aggregated EMERGY input source data tables similar to Tables 2 and 3 that follow.

Environmental Value Engineering Application Example

The application example presented in this paper is the comparison of two built environment system alternatives. Alternatives selected are the following two types of exterior wall systems for a building: a concrete masonry wall and a site cast concrete tilt-up wall. For comparison purposes, both walls are standardized at one square meter in surface area and eight inches in thickness. EMERGY calculation procedures are completed for each wall system alternative and the results are entered into EMERGY input tables that are summarized in aggregated EMRGY input data tables (see Tables 2 and 3). Referring to the corresponding data given in Tables 2 and 3 that follow, a comparative assessment of the two exterior wall alternatives can be made.

The aggregated EMERGY input source data tables provide information on the environmental contribution and impact of built environment alternatives in units of solar EMERGY (SEJs) during the alternative's life cycle. Life cycle phase totals are given in the right column of each table. Total system EMERGY for the concrete masonry and concrete tilt-up exterior wall systems are provided at the bottom of Tables 2 and 3, respectively.

The aggregated EMERGY input source data tables can be used to locate high EMERGY concentrations that occur during the 10 phase life cycle of each alternative. Research can be focused on EMERGY reductions at these high concentrations. Decisions toward sustainability should balance the inputs of environment, fuel energy, goods, and services (labor).

TABLE 2. Aggregated EMERGY input source data for concrete masonry exterior wall system (SEJ per Square Meter)[4].

EVE PHASE	**Environ.**	**Fuel**	**Goods**	**Services**	**Total Phase**
A-C.	6.83E11	6.93E12	1.91E11	2.78E12	1.06E13
D. Design	1.05E9	1.11E10	0	3.40E11	3.52E11
E. Comp. Produc.	0	1.07E11	1.06E10	1.05E11	2.23E11
F. Construction	0	1.05E11	1.60E9	8.96E12	9.07E12
G. Use	0	0	0	0	0
H. Demolition	0	8.34E11	1.24E11	1.45E12	2.41E12
I. Recycling	0	0	0	0	0
J. Disposal	4.80E8	2.73E11	1.55E10	5.63E11	8.52E11
TOTAL SYSTEM					2.35E13

TABLE 3. Aggregated EMERGY input source data for concrete tilt-up exterior wall system (SEJ per Square Meter) [4].

EVE PHASE	**Environ.**	**Fuel**	**Goods**	**Services**	**Total Phase**
A-C.	1.03E12	7.55E12	2.30E11	3.18E12	1.21E13
D. Design	1.08E9	1.14E10	0	3.49E11	3.62E11
E. Comp. Produc.	0	0	0	0	0
F. Construction	0	1.26E11	3.07E10	2.92E12	3.08E12
G. Use	0	1.26E9	1.26E10	2.67E11	2.81E11
H. Demolition	0	1.46E12	2.17E11	2.56E12	4.24E12
I. Recycling	0	0	0	0	0
J. Disposal	5.73E8	3.04E11	1.73E10	6.25E11	9.47E11
TOTAL SYSTEM					2.10E13

Concluding Remarks

Selection of the built environment alternative with the lowest total system input EMERGY minimizes environmental impact and leads toward a sustainable society. Inputs of environment, fuel energy, goods, and labor are limited and their use should be optimized.

The purpose of this paper has been to present Environmental Value Engineering as an environmental life cycle assessment methodology that uses a systems approach to account for and compare total inputs consumed by built environment alternatives. Use of an environmental life cycle assessment methodology for assessment and selection of built environment alternatives toward sustainable development, should be included as part of engineering education. Environmental Value Engineering offers an organized educational platform to fulfill this need.

The methodology can be taught to students for assessment of a variety of built environment systems at various levels of system detail. An engineering education should prepare graduates to properly consider the environmental impact of their decisions toward sustainable development.

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Biography

WILFRED H. ROUDEBUSH

Associate Professor in the Construction Management and Technology program at Bowling Green State University, Bowling Green, Ohio. Registered Architect with Bachelor of Architecture, Master of Science in Architectural Engineering, and Ph.D. in Architecture.