LIFE CYCLE ASSESSMENT FOR EVALUATING GREEN PRODUCTS AND MATERIALS

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ABSTRACT
Life Cycle Assessment (LCA) is used to compare four green building products with their traditional counterparts, including Insulating Concrete Forms (ICFs), Permeable Pavement Systems (PPS), Compact Fluorescent bulbs (CFLs), and HydroProducts' SteamSaver. To the extent that existing data allows, the LCA will explore the impacts that different life cycle stages (i.e. raw materials extraction, production, construction, use, and maintenance) have on the energy use of the comparative products. Each case study elucidates the non-uniformity of green building products and the importance of evaluating all phases of the LCA as well as impacts other than energy use in order to make any conclusions or recommendations about the 'greenness' of green building products. This paper explores the ability of LCA to evaluate green building products and materials and evaluates the importance of different stages of products' life cycle to the overall energy use. Impacts related to other environmental impact categories, such as water and air quality, are also discussed.
Keywords: life cycle assessment, LCA, green building products, lighting, CFL, incandescent, insulating concrete forms, ICF, permeable pavement, steam.

1 INTRODUCTION

The number of green buildings is increasing; as of January 2009, the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) had 17,450 registered projects [1]. Projections of the number of green building projects continue to rise [2]. According to FMI (nation's largest provider of management consulting and investment banking to the worldwide construction market), one of the factors driving the growth of green buildings is the unprecedented government initiatives [3]. For example, President Obama recently announced some of his green initiatives, such as modernizing and greening schools, greening federal buildings, weatherization assistance programs, and green job training.

LEED certifies buildings, not products; however many different labels and rating systems have sprouted up for green building products. Green building products can be measured based on carbon footprint, energy consumption, fair labor, food safety, local sourcing, sustainable forest management, sustainably grown, indoor air quality, etc. With numerous definitions of 'green' products, it is difficult to compare products.

The appropriate use of the life cycle assessment (LCA) framework can effectively determine energy usage and greenhouse gas emissions for the building phases of raw material extraction and manufacturing, construction, and use. To evaluate the sustainability of green building products, the LCA must include the entire life cycle from raw materials extraction to use and ultimately to end of life. Bilec [4] has shown that the construction phase, while not as significant as the use phase, it is as important as other life cycle stages. Unfortunately, life cycle assessment data for the construction phase is limited and is virtually non-existent for construction of green buildings [5].

The use phase of green buildings and products often dominate the life cycle environmental impacts. The U.S Department of Energy's (DOE) Energy Efficiency and Renewable Energy (EERE) has a multitude of software for energy modeling. Various tools are available for the whole building analysis, code compliance and also for specific applications like calculating the envelope energy requirements, heating, ventilating and air conditioning (HVAC) systems sizing, and the lighting system energy needs [6]. Some tools enable the calculation of individual buildings' energy envelope (e.g. eQuest) or national building energy usage (e.g. the Department of

Energy's NEMS model [7, 8]). However, it is rare that these tools incorporate energy savings potential for green building products and newer forms of green building design. The McKinsey & Company 2009 report evaluates the potential energy savings and payback period of specific products. The report includes residential, commercial, and industrial sectors and compares different strategies and ranks them for the specific sector.

This paper explores the ability of LCA to evaluate green building products and materials and evaluates the importance of different stages of products' life cycle to the overall energy use. Impacts related to other environmental impact categories, such as water quality, are also discussed.

2 CASE STUDIES

The LCA of four green building product case studies is presented including Insulating Concrete Forms (ICFs), Permeable Pavement Systems (PPS), Compact Fluorescent bulbs (CFLs), and the SteamSaver. Each case study elucidates the non-uniformity of green building products and the importance of evaluating all phases of the LCA in order to make any conclusions or recommendations about the 'greenness' of green building products.

2.1 Insulating Concrete Forms

Insulating concrete forms (ICF) are expanded or extruded polystyrene forms for poured concrete walls that stay-in-place as a part of the wall; plastic ties hold the forms together. The forms fit together vertically with interlocking tongue and groove joints and are easily stacked. The left-in-place forms provide insulation, sound barrier, and drywall backing for interior walls as well as backing for traditional exterior façade materials. ICFs typically limit the amount of air infiltration, and the concrete acts as a thermal mass that minimizes the heating and cooling variations; R-values are reported to range from 20 to 50 [9]. ICFs can reduce the amount of waste during construction, as the forms are integral with the structure. Since ICFs are a low-density material, the transportation costs can become very high and to curtail the transportation issue, many ICF manufacturers are centrally and strategically located in the United States, minimizing travel distances. Previous studies have shown that the maximum energy is consumed when the house is in use for 50 years of its serviceable lifetime [10, 11]. Building products like ICF have inherent insulation properties which allow for reduction in energy consumption when the house is in use.

2.2 Permeable Pavement

There are many different types, shapes and sizes of permeable pavement systems (PPS) including porous asphalt, porous concrete, and jointed block pavers [12]. Choice of type is highly dependant on the intended use. Porous surfaces are designed to have holes or spaces between them to allow rainwater to infiltrate the pores into the ground. Traditional asphalt and concrete surfaces are not porous and cause water to collect on and run off of the surface, typically as stormwater runoff. The water management abilities of PPS are a great advantage over impermeable pavement surfaces.

2.3 Lighting

Electrical lighting is estimated to account for 25-40% of the total electrical energy consumption for typical commercial and institutional buildings located in the United States [13]. Incandescent lightbulbs (ILs) versus compact fluorescent lightbulbs (CFLs) are compared for use in lighting. In the US, the Energy Independence and Security Act of 2007 (EISA) calls for the phasing out of incandescents by 2014 as well as manufacturing improvements for CFLs and alternatives [14]. It is well documented the CFLs use much less electricity to provide illumination when compared to incandescent bulbs [15]. However, CFLs have complex and energy-intensive manufacturing processes and contain mercury gas within the bulb. Proper disposal of CFLs may be imperative to minimizing their environmental impacts [16]. Mercury is also a problem for incandesents as it is produced during the use of electricity from Coal-fired power plants since this process emits mercury.

2.4 Steam

It is important to evaluate buildings' efficient use of steam since nearly half of all energy consumed by manufacturing/industrial concerns in the US is directed toward steam production [17]. Other noteworthy uses of steam within buildings include HVAC systems for municipal, federal and commercial buildings. Significant opportunities exist to examine the energy use and distribution within buildings, especially within steam-based systems. Approximately 20% of the steam leaving a central boiler plant is lost via leaking traps in typical space heating systems [18].

The fourth case study evaluates a potential green building product, the SteamSaver, and its energy savings potential. Hydroproducts Company's SteamSaver system replaces most traditional mechanical steam traps with a design that essentially eliminates maintenance of traditional steam traps while potentially reducing buildings' energy consumption 10 to 25%. HydroProducts' Steam Saver utilizes a venturi type design, which allows for it to be simpler, smaller, and less prone to maintenance than traditional traps. According to HydroProducts, conventional traps on average last 1/3 of the time and require significantly more labor ours to install and maintain compared to SteamSaver traps [19].

3 METHODS

Life Cycle Assessment (LCA) is used to compare four green building products with their traditional counterparts. To the extent that existing data allows, the LCA will explore the impacts that different life cycle stages (i.e. raw materials extraction, production, construction, use, maintenance, and end of life) have on the energy use of the comparative products.

3.1 Life Cycle Assessment (LCA)

Life Cycle Assessment provides a comprehensive and quantitative analysis of the environmental impacts of a product or process throughout its entire life cycle. LCA is a powerful and widely used tool for measuring the sustainability of an enterprise or concept and for informing decisions with respect to cost, sustainability and environmental considerations. An LCA quantifies the environmental impacts of a product or process and can identify the most benign technologies among an array of options. Through use of LCA, it is possible to observe which stage (or stages- i.e. creation, use, or end of life) causes the most impact, and may offer suggestions to minimize impacts throughout a product's life. Established guidelines for performing detailed LCAs are well documented [20-22]. As defined by the ISO 14040 series, LCA is an iterative four-stage process: (1) Goal and Scope Definition defines the extent of analysis and the system boundaries, (2) Inventory Analysis documents material and energy flows which occur within the system boundaries (also called the life cycle inventory or LCI), (3) Impact Assessment characterizes and assesses the environmental effects using the data obtained from the inventory (also called the life cycle impact assessment or LCIA), and (4) Interpretation and Improvement identifies opportunities to reduce the environmental burden throughout the product's life.

3.2 Model and Data Sources

The LCI data utilized to calculate life cycle energy consumption for the green building products and their traditional counterparts is presented in Table 1. The end of life was not included for any product; thus this is a cradle to gate LCA for energy consumption. Ecoindicator 99 was used to calculate the total life cycle fossil energy use within the SimaPro v.7 life cycle assessment software [23]. The functional units for the analysis are given in Table 2.

A summary of the assumptions related to specific products is given in Table 1, while system assumptions are discussed below. Steam trap raw materials extraction and manufacture (RM & Manuf) was assumed from manufacturer information from publicly available data from Hydroproducts [19] and Armstrong [24]. Construction or installation was negligible for steam traps. Use and maintenance (Use & Maint) data was assumed for both systems from Hyrdoproducts and DOE reports on steam failure and related energy losses that occur within 1 year.

Table 1: Life Cycle Inventory data resources and assumptions made in calculating the life cycle energy consumption of each product.

Product	Data resources	Assumptions
Bucket Trap	ecoinvent, Armstrong bucket trap composition, [25, 26]	Hydroproducts' data for steam losses during use for 1 yr, [27], lifetime = 3 yr
Steamsaver	IDEMAT, Hydroproducts' data for use & maintenance	Assume no steam loss. Lifetime = 10 yr
IL	ecoinvent, energy star	1000 hr lifetime, 15W
CFL	ecoinvent, energy star	8000 hr lifetime, 60W
Asphalt	ecoinvent, Portland Cement Assn, [28]	95% aggregate, 5% bitumen
PPS	ecoinvent, Portland Cement Assn, [28]	15% Portland cement, 39% aggregate, 24% sand
Wood	ecoinvent, Franklin, eQuest	1sqft = 7.2 kg wood, 0.45 kg insulation
ICF	ecoinvent, eQuest, manufacturer data	1sqft = 48 kg concrete, 0.28 kg PS, 0.28 kg PP

Table 2: Functional units for product comparisons.

Product	Functional Unit
Steam traps	1 trap
Light bulbs	kWh
Pavements	??
Wall sections	1 house

IL and CFL raw materials and manufacture were calculated within SimaPro based on the materials that make up each bulb. Bulbs were dismantled within the lab to determine material weights and types, shown in Table 3. Data is presented for lightbulb use in a building, which was assumed to have 10,000 light bulbs. Construction, or installation, was negligible and not included.

Asphalt and PPS raw materials and manufacture were calculated based on the mix of raw materials given in Table 1. The construction stage represents the laying of the pavement. Use and maintenance was not included in this analysis.

The raw materials and manufacture LCI data for 1 square foot of wood and ICF was linearly scaled up to the size of one house. Construction was neglected for the wood and ICF comparison. The house is modeled as approximately 2500 sq ft and its lifetime was assumed to be 40 years.

Table 3: Material composition of light bulbs.

Material	Amount
CFL	
HDPE A	16.7 g
Glass (white) B250	20.5 g
Aluminum 50% rec. B250	3.1 g
Copper I	0.3 g
Glass (brown) B250	5.3 g
PVC suspension A	0.1 g
Mercury gas	5 mg
Incandescent	
Glass (white) B250	21.7 g
Aluminum 50% rec. B250	1.6 g
Copper I	0.1 g
Glass (brown) B250	2.4 g

4 RESULTS

The fossil energy consumption throughout the life cycle of the green building products and their traditional counterparts is presented in Figure 1. Overall, there are no consistencies among the green building products as to which life cycle stage typically contributes the most to the overall life cycle energy consumption. For products that rely heavily on energy use during the use and maintenance (Use & Maint) of the final product, the use phase dominates the LCA. Steam trap production (RM & Manuf) contributes minimally to energy use. In fact, the resultant energy use is 100% attributed to the maintenance (or lack thereof) when steam traps fail. This life cycle energy use is very easily reduced with minimal maintenance investments. Asphalt and PPS have minimal construction energy requirements, however use and maintenance were omitted from the LCI.

While many comparisons of green building products focus on energy use, life cycle cost, and greenhouse gas emissions, other important environmental impacts are often neglected. Table 4 discusses some of these important factors for each product.

ICFs provide an interesting case study of a conceptually non-‘green’ product that is made out of concrete and polystyrene that prove to have better life cycle environmental impacts when compared to wood, a product that might conceptually seem ‘green’ because it is made out of renewable materials.

Energy use for PPS compared to their traditional counterparts, such as concrete or asphalt pavement, is not an ideal metric for evaluating these systems. As shown in Figure 1, their energy requirements are similar. However, the major environmental benefits that are achieved with the ‘greener’ product, PPS, is stormwater runoff management. Stormwater runoff is not a typical category in LCAs. For PPS, the benefits of water management should be evaluated within a unique LCIA category focus on stormwater management to ascertain its true benefits.

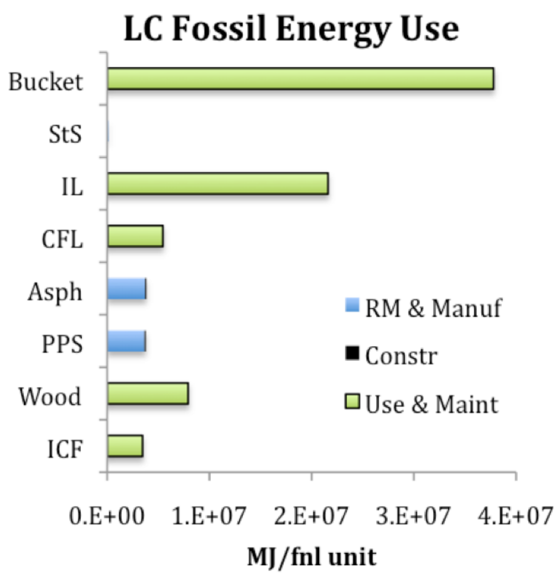

Figure 1: Comparison of the Life Cycle Fossil Energy Use for green building products and their traditional counterparts. (StS = Steamsaver, IL = incandescent light bulb, CFL = compact fluorescent light bulb, Asph = asphalt, PPS = permeable pavement system, ICF = insulating concrete form, RM & Manuf = raw materials and manufacture, Constr = construction, Use & Main = use and maintenance)

The use of energy consumption to compare types of lighting does not capture the environmental impacts of the highly debated mercury emissions from CFLs. While research has shown that the use of ILs that rely on coal-derived electricity emits more mercury from their energy consumption than CFLs, it is still important to assess how well the product take-back systems in place for CFLs minimize their mercury emissions [16].

The incorporation of the end-of-life or disposal as a life cycle stage will be important to accurately evaluate the life cycle environmental impacts of green building products. While this stage was omitted from this study, one might anticipate that the end of life for ICFs that includes recycling concrete might improve its life cycle environmental impacts even more when compared to wood. However, these improvements are expected to be minimal over the entire life of the structure. The end-of-life may significantly impact asphalt versus PPS, while disposal is likely not a large part of the steam trap and life cycle.

In summary, while life cycle energy consumption is a useful metric for comparing the energy use for different products, it should not be used as the sole metric for comparison. Other environmental benefits should also be assessed, including but not limited to, air quality and water quality.

Table 4: Summary of benefits and tradeoffs for green building products.

Green Building Product	Traditional Product*	The Benefit	The 'Catch'	The Important Life Cycle Stage
1. ICF	Wood*, concrete masonry unit (CMU)	Tremendous use-phase energy savings	Made of non-green materials (i.e. concrete, PS)	Use: energy
2. PPS	Concrete, asphalt*	Reduces stormwater runoff	Reductions in stormwater runoff not typically incuded in LCIA categories	Manufacture: energy Use: water
3. CFL	Incandescent*	Use-phase energy savings	Disposal of CFL (contains Hg) may cause problems	Use: energy Disposal: Hg
4. SteamSaver	Bucket*, other steam traps	Tremendous use-phase energy savings	Improvements related to maintenance are hard to quantify	Use: energy losses and maintenance

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