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Comparing Exterior Wall Finishes Using Life-Cycle Assessment

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ABSTRACT
Selecting products that are environmentally friendly can help reduce the negative environmental impacts associated with the built environment. However, the process can be difficult. Life-cycle assessment (LCA) is an approach used to measure the environmental performance of a product or service by considering all stages of a product's life-cycle from extraction of raw materials to its end of life. Many products that claim to be environmentally friendly are based on a single life-cycle stage or environmental impact. These claims are often misleading as they do not consider other life-cycle stages or other environmental impacts associated with the products. This study examines alternative exterior wall finishes for a traditional single-family home in the State of Ohio from an LCA approach to determine which finishes are friendlier on the natural and built environment. Advantages and disadvantages of exterior wall finishes including aluminum siding, brick, wood siding, fiber cement siding, stucco, and vinyl siding have been investigated, as well as the impact each finish has on each of the life-cycle stages. Their life-cycle environmental impacts during various life-cycle stages are compared using the BEES (Building for Environmental and Economic Sustainability) software developed by the National Institute of Standards and Technology. Each of the exterior wall finishes were compared in the following categories: overall life-cycle environmental impacts, global warming potential, recyclability, service life, and the cost of material and labor. Not one of the materials scores the best in every category. While vinyl siding does not have much potential for recycling or a long service life, it performs well in other categories and appears to be a better option from an environmental and cost perspective overall.

KEYWORDS
Exterior Wall Finishes; Life-cycle Assessment

INTRODUCTION
The construction industry consumes about 50% of the natural resources extracted from the earth. The process of extracting raw materials leads to resource depletion, creates pollution and landfill waste, and contributes to biological diversity losses. Also, transporting raw materials to manufacturing plants, and turning those materials into products, generates additional pollution and requires energy consumption resulting in higher greenhouse gas emissions. Products typically generate wastes during installation or have short service lives that result in disposal and the manufacture of replacement products. Energy consumption by the built environment is responsible for 40% of greenhouse gas emissions worldwide, so selecting building products that are environmentally friendly is one way to help reduce the negative environmental impacts associated with the built environment (Lippiatt, 2007). When considering products, people will typically look at the cost, lifespan, and product maintenance. However, people tend to only consider the end product and are not aware of the negative impacts that these products have on the environment from a life-cycle perspective (Robertson, 2008). By implementing life-cycle assessment (LCA), it is possible to optimize aspects of a product from the extraction of raw materials to the end of life. LCA helps to look

at the ways in which to improve environmental processes, ways in which to prevent adverse environmental impacts, how to enhance the quality of life, and ways to allow people to live in a healthy environment. In comparison between the findings of this study and existing studies, a lack of comparable research was discovered. Existing residential LCA studies on exterior walls tend to study entire wall assemblies rather than just the exterior wall finishes. The purpose of this study is to consider only the exterior wall finishes for a traditional single-family home in the northeast Ohio, United States. These finishes are compared to help aid in the selection of finishes that are environmentally friendlier from an LCA approach. The cost of the materials and installation are compared as well.

METHODS

The project is a 2-story residential house, located in a subdivision in the northeast Ohio. The house contains 4 bedrooms, 2.5 baths, and a 2-car attached garage. The house is constructed of 2x4 wood framing with batt insulation. The current materials on the envelope of the house include vinyl siding and asphalt shingles, shown in Figure 1. The finishes in this study include aluminium siding, brick, wood siding, fiber cement siding, stucco, and vinyl siding.

Figure 1. House used for the study (SketchUp Warehouse model by Paulwall)

The Building for Environmental and Economic Sustainability (BEES) software, developed by the U.S. National Institute of Standards and Technology, was used to compare the overall environmental performance of the exterior wall finishes according to their life-cycle stages.

BEES generates environmental performance scores for building products sold in the United States. The scores generated help with selecting products that are environmentally preferred. Manufacturing of a product involves several unit processes with inventory flows. The basis for the unit of comparison is the functional unit, which for this study will be 1 ft^2 of product lifetime for a 50-year period. Inventory analysis involves quantifying the inventory flows for a product. Data categories are used to group the inventory flows. For generic products, as used primarily in this study, assumptions concerning the associated unit processes were verified through industry experts.

The impact assessment quantifies the potential contribution of a product's inventory flows to a variety of environmental impacts. Twelve impacts include global warming, acidification, eutrophication, fossil fuel depletion, habitat alteration, criteria air pollutants, indoor air quality, human health, smog, ozone depletion, ecological toxicity, and water intake are addressed. Inventory flows contributing to each impact have been quantified and characterized in terms of U.S. flows per year per capita. Adding all characterized flows for each impact results in impact category performance measures. These measures represent a baseline against which to compare the environmental impacts of a product.

During interpretation, the normalized impact assessment results are analyzed. To compare the overall environmental performance of the alternative products, the performance scores for all the impact categories are synthesized. This is achieved by weighting each of the impact categories by its relative importance to the overall environmental performance, and then computing the weighted average impact score. The weighting used for this study is based on the EPA Science Advisory Board study (USEPA, 2000). Highest-risk problems include global warming and habitat alteration. High-risk problems include indoor air quality, ecological toxicity, and human health. Medium-risk problems include ozone depletion, smog, acidification, eutrophication, and criteria air pollutants. Fossil fuel depletion and water intake were not explicitly considered as impacts (Levin, 1996). These classifications are then converted into numerical importance weights using a method known as the analytic hierarchy process (ASTM International, 2002). Finally, the materials and installation costs are compared for these alternative exterior wall finishes using 2016 construction cost data (RS Means, 2016).

RESULTS AND DISCUSSIONS

The first step in the BEES assessment is to specify the analysis parameters. For this part of the study, other environment performance of the exterior wall finishes is being considered, so the environmental performance is set at 100% while the economic performance is set at 0%. In the building element for comparison section, shell is the major group element, exterior enclosure is the group element, and exterior wall finishes is the individual element. The product alternatives represent the six exterior wall finishes to be compared. The transportation distance represents the number of miles from the manufacturer to the site. Manufacturer locations and site locations vary for each analysis, so a default mileage, which represents an average, was used.

After selecting all the products for LCA comparison, the analysis was completed. The analysis looked at the overall environmental performance, the overall global warming potential, and the effect that each finish has on environmental impacts. Refer to Figures 2-4 for the results of the comparisons. The results are based on a performance score and do not represent absolute performance. Instead, these scores represent proportional differences in performance among the alternatives. The lower the number of the performance score, the more environmentally friendly the product is (Lippiatt, 2007).

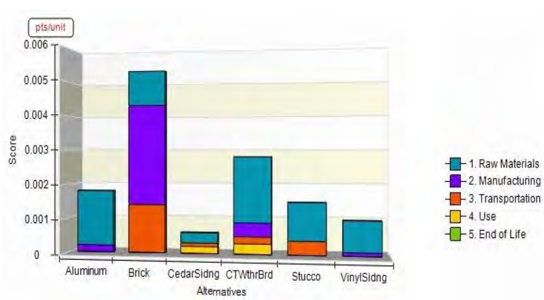

Figure 2. Environmental performance

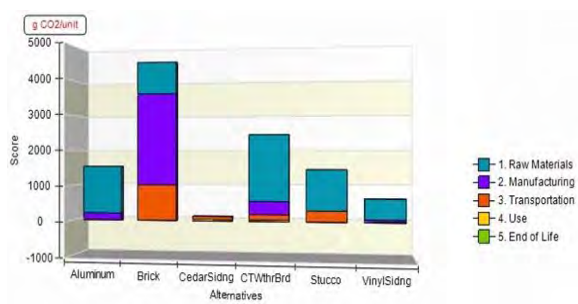

Figure 3. BEES global warming results

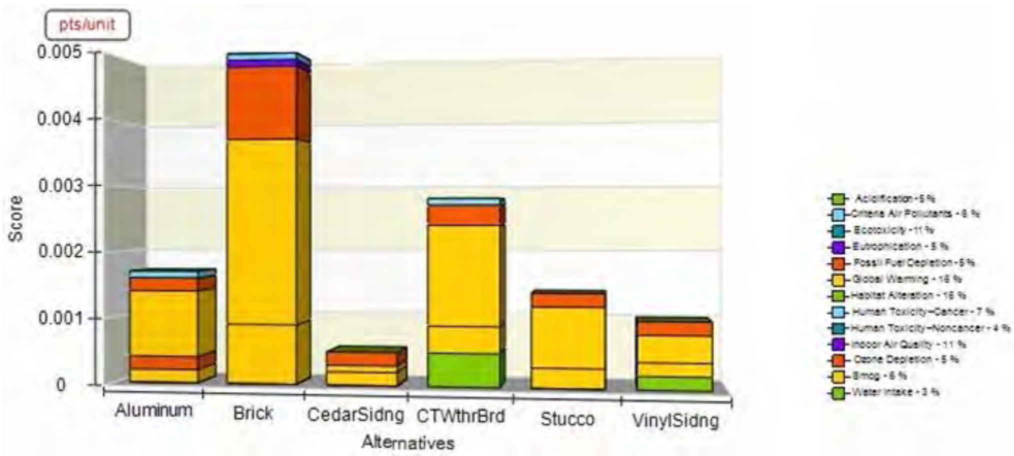

Figure 4. BEES results of each finishes' effect on environmental impacts

The results of the exterior wall finishes analyzed for comparison shows that of the five life-cycle stages, the extraction of raw materials has the greatest negative impact on the environment of each material except for brick. Wood siding has the least harmful impact on the environment, with a total performance score of 0.0006. Brick has the most harmful impact on the environment with a total impact performance of 0.0053. Viewing the global warming potential from these life-cycle stages, the results show that the extraction of raw materials is the greatest contributor to the negative impact on global warming of each material except for brick and wood siding. Wood siding has the least harmful impact on global warming with a total performance score of 126. Brick has the most harmful impact on global warming with a total performance score of 4513. The life-cycle stages of the finishes show that global warming has the greatest negative impact on the environment. Wood siding contributes the least to global warming with a total performance score of 0.0005. Brick contributes the most to global warming with a total performance score of 0.0050.

Based on the results from the BEES comparison studies, the exterior wall finish that is overall the most environmentally friendly, and contributes the least to global warming is wood siding. The exterior wall finish that is overall the least environmentally friendly, and contributes the most to global warming is brick. The other finishes, in order from most environmentally friendly to least environmentally friendly from all life-cycle stages combined are vinyl siding, stucco, aluminum siding, and fiber cement siding. Raw material extraction and manufacturing of these finishes are the life-cycle stages which contribute the most to a negative environmental impact. These two life-cycle stages also greatly impact the global warming potential and are the largest contributors of carbon dioxide emissions.

Some information to consider when performing LCA is that values associated with each model are representative of the year of the model. Data originating from surveys and/or forms submitted by industries to governments for national statistical purposes can be incomplete, thus underestimating actual data values. Economic input-output coefficients for stable industries may be similar to past coefficients, but may vary over time for rapidly changing industries. Also, environmental data can vary due to changes in efficiency, pollution regulations, or production levels (Carnegie Mellon University, 2016). In addition, products tend to be grouped into a single industry sector if their production requires a similar process, thus resulting in data and dissimilar products taking on contributions and impacts of another product. While uncertainties in data do not imply that LCA studies are unreliable, these uncertainties should be understood and the LCA results recognized (Williams, 2009).

The house in this study has a surface area of 3,292 ft² excluding all doors and windows. Accounting for a 5% material waste and rounding up to the nearest 100 ft², the total surface area increases to 3,500 ft². The cost of materials falls within a price range, so the lowest cost of each material and the highest cost of each material is calculated (Anderson, 2013; RS Means, 2016). The total costs exclude overhead and profit.

Table 1. Costs of Materials and Installations

	Material ($/ft²)		Labor ($/ft²)		Total ($/ft²)		Material Total ($)		Material + Installation Total ($)	
	Low	High	Low	High	Low	High	Low	High	Low	High
Aluminum	$1.63	$4.73	$1.96	$1.96	$3.59	$6.69	$5,705	$16,555	$12,565	$23,415
Brick	$4.00	$7.00	$7.00	$10.00	$11.00	$17.00	$14,000	$24,500	$38,500	$59,500
Wood (Cedar)	$3.79	$6.75	$1.03	$1.03	$4.82	$7.78	$13,265	$23,625	$16,870	$27,230
Fiber Cement	$1.19	$4.12	$1.82	$1.11	$3.01	$5.23	$4,165	$14,420	$10,535	$18,305
Stucco	$1.00	$1.00	$1.30	$1.50	$2.30	$2.50	$3,500	$3,500	$8,050	$8,750
Vinyl Siding	$0.72	$1.62	$1.48	$1.41	$2.20	$3.03	$2,520	$5,670	$7,700	$10,605

The costs of the exterior wall finishes in order from the cheapest to the most expensive are vinyl siding and stucco, fiber cement siding, aluminum siding, wood siding, and brick. Each of the exterior wall finishes were compared in various categories. Green represents the best in each category, yellow represents second to best, and red represents the worst in each category. Refer to Table 2 for the category comparisons.

Table 2. Overall Comparison

	Life-Cycle Impacts	Global Warming Potential	Recyclability	Service Life (Years)	Material + Install ($ Low)	Material + Install ($ High)
Aluminum	0.0018	1,538	100%	80	$12,565	$23,415
Brick	0.0053	45,134	75%	100+	$38,500	$59,500
Wood (Cedar)	0.0006	126	0%	40	$16,870	$27,230
Fiber Cement	0.0028	2,436	0%	50+	$10,535	$18,305
Stucco	0.0015	1,458	0%	100+	$8,050	$8,750
Vinyl Siding	0.001	655	0%	40	$7,700	$10,605

Not one of the materials scores the best in every category. Therefore, the best material cannot be selected without weighing the pros and cons. Brick has the worst score for life-cycle impacts and global warming potential, as well as the most expensive in cost compared to all the other materials. Brick has an advantage since 75% of it can be recycled at its end of life. Also, brick has a service life that can last over 100 years. However, a house's typical lifetime is about 60 years, so the service life far exceeds the house's lifetime. Aluminum siding does not have the worst scores in any of the categories, but requires continuous painting and can dent very easily. Stucco's life-cycle impacts and global warming potential fall near the middle, so environmentally, it is not the worst material, nor is it the best material. However, stucco is rarely used in the northeast Ohio. Fiber cement siding also falls near the middle range of the environmental impacts, but like aluminum siding and stucco, fiber cement is not a very common material in the northeast Ohio when compared to vinyl siding. Wood siding has the lowest life-cycle impacts and contributes the least to the global warming potential. It is more expensive than vinyl siding and is not typically recycled. Its service life is shorter than that of a house's typical lifetime, so the siding would need to be replaced at least once. Also, wood siding requires continuous painting or staining. While the material does not have much potential for recycling or a long service life, it does well in the other categories. Vinyl siding is a close second to wood as the best material according to life-cycle impacts and global warming potential, plus it is an affordable material. The service life of vinyl siding is the shortest compared to those of the other materials but it can be replaced at the end of its service life, replacement material can be produced, and it will still have an overall life-cycle impact and global warming potential lower than that of aluminum, brick, wood, and fiber cement. Also, vinyl siding does not require painting or extensive maintenance.

While research shows that wood, fiber cement, stucco, and vinyl siding do not have much potential for recycling at end of life (Lippiatt, 2007), measures are being taken to prevent various building materials from ending up in landfills. Local regulatory measures, disposal fee increases, education, and green building are driving the market toward building material recovery. By recovering used building materials from waste streams, materials can be re-manufactured and refurbished (Liming, 2018).

CONCLUSIONS

Overall, vinyl siding appears to be the best option from an environmental and cost perspective. Based on the results carried out in this study, the most affordable material is not necessarily the most environmentally friendly. It is difficult to select a material that has both an appealing price tag as well as less of a negative impact on the environment. However, it is possible to weigh the options to responsibly select a material.

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