Life Cycle Assessment of Flooring Materials

A Guide to Intelligent Selection

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August 25, 2009

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Background

Homeowners have a number of flooring options from which to choose. Options include ceramic tile, vinyl, linoleum, bamboo, hardwood, carpet made of natural or a variety of synthetic fibers, and more. The differences in environmental impacts between these various options are large. For those interested in minimizing the environmental impacts associated with their choice of flooring material, finding reliable information about the impacts and trade-offs can be daunting.

This report examines available life cycle assessment data for a number of flooring products. Research findings and assessment data from around the world are reported and summarized.

Life Cycle Assessment

A life cycle assessment (LCA) provides a mechanism for systematically evaluating the environmental impacts linked to a product or process. Information gained through an LCA can be used to guide process or product improvement efforts. LCA-based information also provides insights into the environmental impacts of raw material and product choices, and maintenance and end-of-product-life-strategies. Because of the systematic nature of LCA and its power as an evaluative tool, it is increasingly being used to aid in the comparison of product alternatives.

An LCA typically begins with a careful accounting of all the *measurable* raw material inputs (including energy), product and co-product outputs, and emissions to air, water, and land; this part of an LCA is called a Life Cycle Inventory (LCI). An LCI may deal with product manufacture only, or may include all stages in production, use, and disposal, including raw material extraction, transportation, primary processing, conversion into finished products, maintenance and repair, and disposal. Analyses are conducted using a uniform set of international guidelines and procedures as published by the International Organization for Standardization (ISO). The beauty of an LCI is that it focuses on factors that are rather precisely measurable, using uniform guidelines for the conduct of analyses. The systematic nature of an LCI, therefore, allows different analysts from different parts of the world to obtain the same results given a certain set of assumptions. For a more complete discussion of the LCA process, see the January 2005 Dovetail report *Life Cycle Analysis: A Key to Better Environmental Decisions*.[1]

Environmental Attributes of Flooring Products

NIST

As a one-stop source of life cycle assessment-based information about flooring options the Building for Energy and Environmental Sustainability (BEES) program of the National Institute of Standards and Technology (NIST) is the most comprehensive resource available today.[2] There are currently 25 floor covering products in the system, of which about half are distinctly different products.

[1] (http://www.dovetailinc.org/files/DovetailLCA0105.pdf)
[2] The BEES program is accessible online (http://www.bfrl.nist.gov/oae/software/bees/) and free to download and use.

Unfortunately, only flooring coverings typically used in commercial buildings and institutions are currently included in BEES, and the program does not yet cover options such as hardwood and bamboo. Nonetheless, information in the BEES system is quite useful for those products covered.

Using BEES yields information regarding twelve environmental attributes, including:

- Global warming
- Acidification
- Eutrophication
- Fossil fuel depletion
- Indoor air quality
- Human health
- Habitat alteration
- Criteria air pollutants
- Ecological toxicity
- Water intake
- Ozone depletion
- Smog

This program also rates overall environmental impact using a system that weights the above attributes according to the degree or seriousness of environmental impact. Users have the option of using weighting factors developed by a BEES Stakeholder Panel or by a Scientific Advisory Panel of the Environmental Protection Agency. Economic comparisons between various product options are also provided. This report assesses nine different floor covering products, as described in Table 1.

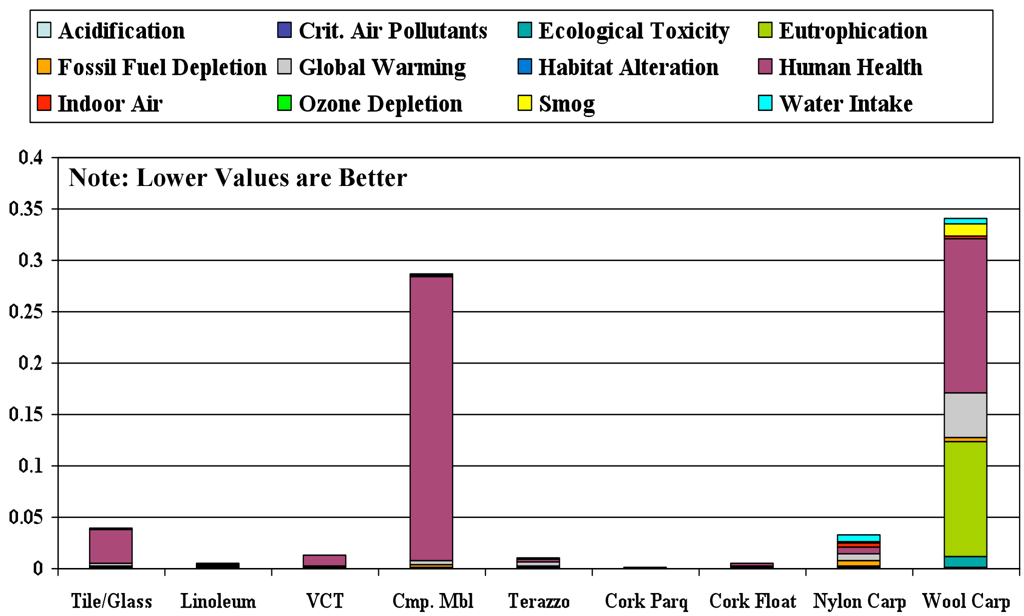
Table 1: Descriptions of the Various Floor Coverings Assessed

Floor covering material	Product description	Principal raw materials	Estimated service life
Ceramic tile with recycled glass	Ceramic tiles 6 in. x 6 in. x 0.5 in. (12.7 mm) thick installed on a 0.5 in. (12.7 mm) layer of latex/mortar.	Clay (25%) and recycled glass (75%).	50 yr.
Linoleum	Sheet linoleum 2.5mm thick (0.098 in.) with jute backing and polyurethane-acrylic finish coat, and applied using a 0.01 in. thick (0.29 mm) acrylate copolymer adhesive.	Wood flour (31%), linseed oil (23%), limestone (18%), jute (11%).	30 yr.
Vinyl composition tile	Vinyl tiles 12 in. x 12 in. x 0.125 in. (0.32 mm) thick with high proportion (84%) of inorganic filler applied with a 0.03 in. (0.79 mm) thick layer of styrene-butadiene adhesive.	Limestone (84%), vinyl resins (12%).	40 yr.
Composite marble tile	Tiles 12 in. x 12 in. x 0.375 in. (0.96 mm) thick made of polyester resin and matrix filler, colored for a marble effect, installed using a 0.5 in. (12.7 mm) thickness layer of latex/mortar blend.	Limestone filler (78%), polyester resin (20%).	75 yr.
Terazzo	Terrazzo 0.375inches (9.5 mm) thick containing a high proportion of inorganic filler, pigment, and epoxy resin that is poured, cured, ground, and polished.	Marble dust and chips (77%), epoxy resin (22%).	75 yr.
Natural cork parquet tile	Natural cork sheet made of waste cork powder generated in making cork bottle stoppers and urethane binder.	Recycled cork waste (93%), urethane binder (7%).	50 yr.
Natural cork floating floor plank	Natural cork planks in tongue and groove pattern made of waste cork powder generated in making cork bottle stoppers, a high density fiberboard backing sheet, and urethane binder. In this case, the cork comes from Portugal.	Recycled cork waste (58%), high density fiberboard (39%), urethane binder (3%).	50 yr.
Nylon broadloom carpet (commercial)	Nylon broadloom carpet with backing material (but no pad) that is installed using two applications (to the back of the carpet and also spot application to the floor space) of latex glue.	The basic raw material is petroleum. The raw materials comprising the carpet and glue are nylon 6.6 (42%), limestone filler (37%), styrene butadiene latex (11%), and polypropylene backing (9%).	11 yr.
Wool broadloom carpet (commercial)	Wool broadloom carpet with backing material (but no pad) that is installed using latex glue.	Wool (58%), limestone filler (28%), styrene butadiene latex (9%), and polypropylene backer (5%).	25 yr.

The BEES product comparisons are based on full life cycle assessments that consider environmental impacts from raw material extraction through product manufacture, transport to the building site, installation, and disposal. Impacts linked to routine cleaning and maintenance are not considered. To account for varied service lives, environmental impacts linked to replacement of the shorter lived products are taken into account.

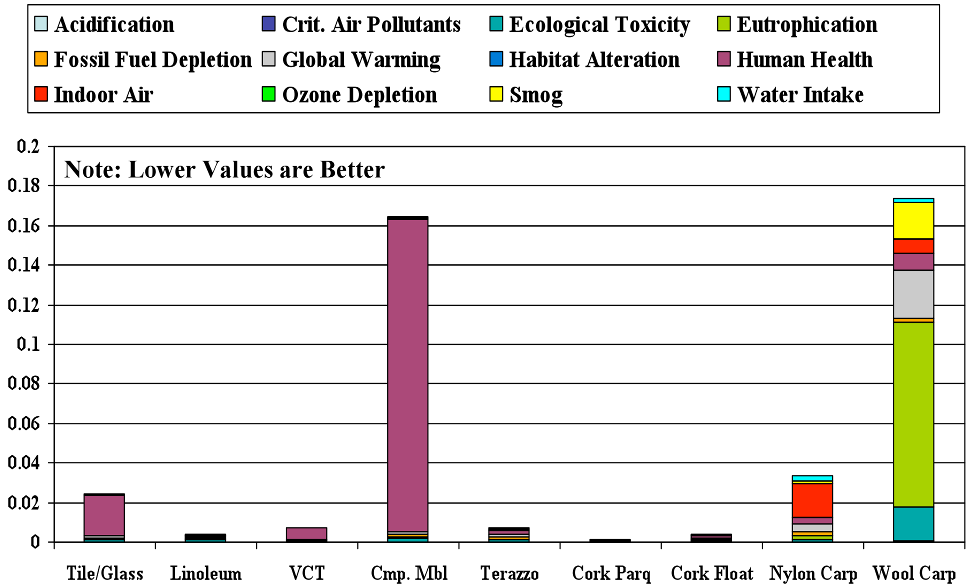
The environmental impacts associated with each of the nine floor covering materials are presented in graphical form in Figures 1 and 2 and in Table 2. When interpreting the impacts, note that *lower values are better*. Results, based on ranking by both the BEES Stakeholder Panel and the Scientific Advisory Panel of the EPA, show the flooring products with the lowest environmental impact from this comparison to be cork parquet, linoleum, and cork floating floor. Those triggering the greatest impacts, and by a substantial margin than other floor covering products, are wool broadloom carpet and composite marble tile.

Figure 1
Environmental Performance of Various Floor Covering Options



Source: BEES 4.0, National Institute of Standards and Technology 2009. Weighting of environmental performance measures by **BEES Stakeholder panel**.

Figure 2
Environmental Performance of Various Floor Covering Options



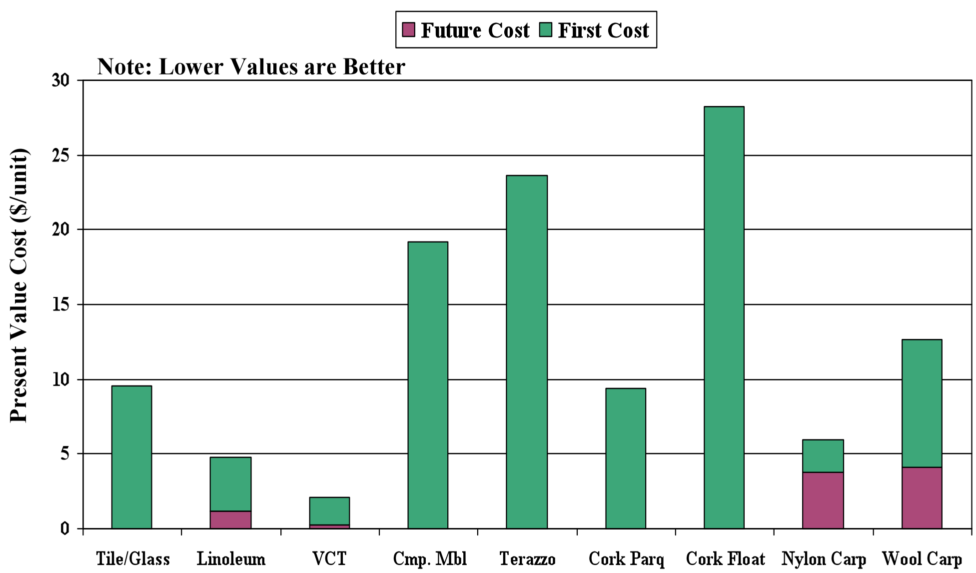
Source: BEES 4.0, National Institute of Standards and Technology 2009. Weighting of environmental performance measures by **EPA Scientific Advisory Panel**.

Table 2
Environmental and Economic Performance Rankings of Various Flooring Products based on the BEES System

Flooring product	Environmental Performance Ranking (1=best, 9= worst) EPA Sci. Adv. Bd.	Environmental Performance Ranking (1=best, 9= worst) BEES Stkhld Pnl	Economic Performance Ranking (1=best, 9= worst) Results same for EPA and BEES Panels	Overall Ranking Assuming Equal Importance of Cost and Environmental Impact (1=best, 9= worst) Results same for EPA and BEES Panels
Ceramic tile with recycled glass	6	7	5	5
Linoleum	3	2	2	2
Vinyl composition tile	5	5	1	1
Composite marble tile	8	9	7	9
Terazzo	4	4	8	6
Natural cork parquet tile	1	1	4	3
Natural cork floating floor plank	2	2	9	7
Nylon broadloom carpet (comml)	7	6	3	4
Wool broadloom carpet (comml)	9	8	6	8

Economic performance measures of the various flooring options are shown in Figure 3. The numbers show that the flooring product (among the nine evaluated) that has the second lowest environmental impact (linoleum) also has the second lowest cost, assuming a 30-year product life. The best product from an environmental perspective (cork parquet) costs about twice as much as linoleum. The cork floating floor product (the third best in the environmental ranking) has the highest cost of any alternative. It is important to remember that the carpeting systems evaluated are commercial systems installed *without a pad*. Thus, both environmental impact and economic performance as presented in the BEES system are significantly lower than would be the case with a typical residential installation. The composite marble product (the second worst environmental performer among the nine products evaluated) also has a high cost. It should be noted that wood floor covering products were not included in this evaluation because they are not currently addressed within the BEES program.

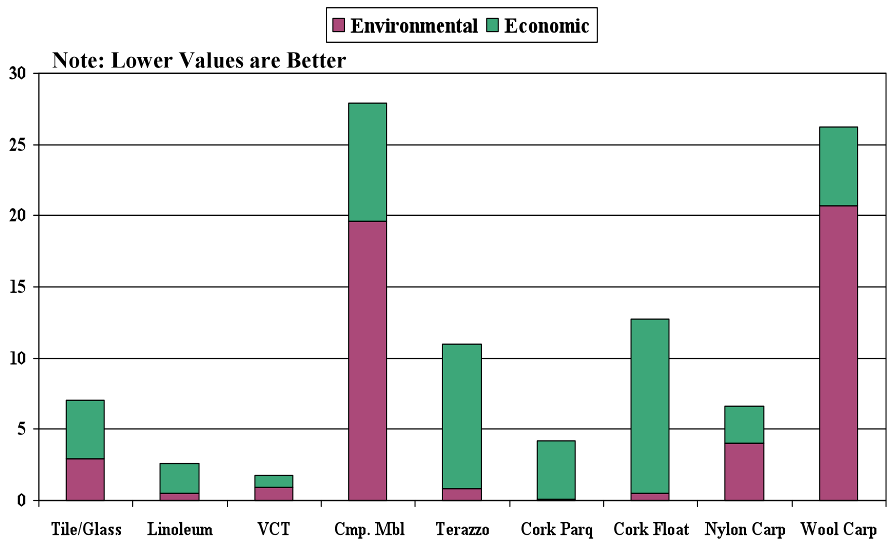
Figure 3
Economic Performance of Various Floor Covering Options



Source: BEES 4.0, National Institute of Standards and Technology 2009. Weighting of environmental performance measures by **EPA Scientific Advisory Panel**.

The following figure (Figure 4) illustrates the results of applying a ranking system that gives equal weight to environmental impact and economic performance (the BEES system allows users to use whatever weighting is desired). Remembering that the lowest values represent the lowest impact and lowest cost, assessment results show vinyl composite tile and linoleum to rank lowest (best) and composite marble and wool carpeting to rank highest (worst) (Table 2).

Figure 4
Overall Performance of Various Floor Covering Options



Source: BEES 4.0, National Institute of Standards and Technology 2009. Weighting of environmental performance measures by **EPA Scientific Advisory Panel**.

It is interesting to note that the two bio-based products, natural cork parquet flooring and natural cork plank flooring, have the lowest environmental impact. Moreover, the principal ingredients (in terms of mass) of the third-ranked product – linoleum – are linseed oil (an oil obtained from the seeds of flax) and wood flour (wood finely ground to the consistency of a powder).

Research Findings

There are other studies of life cycle impacts of flooring products in addition to the research upon which the BEES system is based. Several of these have been conducted in Europe where there is considerable activity in LCA research. For instance, Althaus and Richter (2001) used LCA to examine fourteen different types of cork flooring. Their results produced similar results to those reflected in the BEES model discussed earlier: the floating floor results in substantially greater impacts than a fixed (glued down) cork floor due to the high density fiberboard that triples the weight of the flooring. They also found that a PVC coating on cork flooring results in far higher environmental impacts, even if it is assumed that non-PVC coated cork flooring is refinished as often as every two years.

Another study of four floor covering products – linoleum, tufted carpet with a woolen pile, tufted carpet with a polyamide pile, and cushion vinyl – that was conducted in the Netherlands (Potting and Blok 1995) compared environmental impacts including depletion of raw materials, embodied energy, global warming, acidification, tropospheric ozone creation, stratospheric ozone depletion, eutropication, production of waste, and impacts on human health. This study showed linoleum to have the lowest environmental impact by a significant margin; there was no clear differentiation in environmental impacts of the other flooring products examined.

A U.S. study of three flooring types – vinyl, cork, and linoleum – by the Georgia Tech Research Institute (Jones 1999) found linoleum to have the lowest impact and vinyl the highest. The following year a study in the Netherlands (Gorree et al. 2000) also examined linoleum flooring, concluding that the environmental impact of this flooring was significantly affected by the coloring used in the linoleum.

One of the more comprehensive life cycle examinations of flooring options was a study conducted at the Chalmers University of Technology, Sweden as part of a graduate degree program. That study (Jönsson 1995) examined the life cycle environmental impacts of three flooring materials: linoleum, vinyl, and solid wood (pine) flooring. Considered in the analysis were production, transport, installation, maintenance, and end-of-life disposal. It was assumed that all flooring materials would be incinerated for energy recovery at the end of useful life – a reasonable assumption in Sweden where this type of energy production is common. This study conclusively showed solid wood flooring to have the lowest impact of the three flooring types studied (Table 3). The analysis also showed wood to be the environmentally-preferable material even if service lives of the three flooring types were assumed to be equal.

Table 3
Findings of a Swedish LCA[a/] of Three Types of Flooring
(Green highlighting indicates lowest environmental impact)

	Type of Flooring		
	Linoleum	Vinyl (PVC)	Solid Wood (Pine)
Estimated service life	25 years	20 years	40 years
Life cycle energy consumption (MJ equiv./m^2)	13	29	-64
Global warming potential (g. CO_2 equiv./m^2)	1600	4174	424
Acidification potential (g. SO_2 equiv./m^2)	13	31	24
Eutrophication potential (g. phosphate equiv./m^2)	1.7	1.3	4.2
Photochemical ozone creating potential (g. ethene equiv./m^2)	2.5	0.9	0
Waste resulting from production of flooring materials and incineration (g./m^2 of flooring material)			
- Ash	555	801	198
- Sector specific wastes	17.2	197	0
- Hazardous waste	236	212	0
Dust generated (g./m^2 of flooring material)	34.5	6.8	1.2

[a/] Jönsson et al. (1995).

Two recent Canadian studies by Peterson and Solberg (2003, 2004) compared greenhouse gas (GHG) emissions associated with production and use of wood and other floor coverings. The first study (2003) compared solid oak flooring and natural stone, finding that the oak flooring resulted in greater energy use (1.6 times that needed for production of the same area of stone flooring), but substantially lower GHG emissions provided that the wood was burned for power at the end of its useful life. The second study compared GHG emissions resulting from production and use of solid oak flooring with GHG emissions resulting from use of wool carpet, polyamide carpet, vinyl, and linoleum. In this comparison, production and use of the wood flooring resulted in lower GHG emissions than any of the alternatives studied. From best to worst the ranking of flooring based on GHG emissions was found to be oak flooring (best) linoleum, vinyl, polyamide carpeting, and wool carpeting (worst).

In those comparisons in which wood flooring products have been among the options considered, the wood products have generally been found to have the lowest environmental impact. As additional work is completed a clearer picture of the life cycle environmental impacts of floor covering options will emerge. A very recent U.S. study of the environmental impacts of producing hardwood lumber

(Bergman and Bowe 2008) is the first step toward inclusion of hardwood flooring life cycle information in BEES.

To date, there have been no LCA studies of bamboo flooring published. As noted, neither bamboo nor solid wood flooring are included in the BEES database, a situation that will hopefully change in the near future.

Table 4 summarizes findings from the life cycle assessment research reported herein. Results consistently show floor coverings made from bio-based materials (wood, cork, linoleum) to have lower environmental impacts than other options. Similarly, carpeting – and specifically wool carpeting – is consistently shown to the the worst option from an environmental point of view. The latter finding is interesting in that wool carpeting is sometimes identified as an environmentally preferable flooring option because it is "natural."

Table 4
Environmental Performance of Various Floor Covering Materials

Floor Covering Product	Relative Environmental Ranking
Wood	Best
Natural cork	↓
Natural cork floating floor	
Natural cork with PVC coating	
Linoleum	
Terrazo	
Stone	
Vinyl	
Ceramic tile	
Nylon (polyamide) carpet	
Wool carpet	Worst

The Bottom Line

Homeowners, commercial building owners, designers, and builders have a large number of floor covering options from which to choose. The differences in environmental impacts between these various options are also large.

For those interested in minimizing the environmental impacts associated with their choice of flooring material, finding reliable information can be daunting. As a one-stop source of life cycle assessment-based information about flooring options the Building for Energy and Environmental Sustainability (BEES) program of the National Institute of Standards and Technology (NIST) is the most comprehensive resource available today.

Life cycle comparisons of flooring alternatives by research groups around the world, including those refected in the BEES database, consistently show biobased flooring products to have lower environmental impacts than other types of flooring. The life cycle environmental impacts associated with producing and using flooring alternatives such as cork, linoleum, and solid wood are clearly lower than other alternatives. Wool carpeting and composite marble exhibit the greatest impacts, and impacts linked to typical carpeting used in residential structures are higher than those shown in the BEES system due to the use of a pad under the carpet layer.

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