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Comparison of Environmental Impacts of Flooring Alternatives

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Executive Summary

Homeowners, commercial building owners, designers, and builders have many floor covering options from which to choose. The differences in environmental impacts between some of these options are substantial.

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 reflected in the BEES database, consistently show global warming potential and other life cycle environmental impacts associated with producing and using plant-based flooring alternatives such as cork and solid wood to be lower than other alternatives. Carpeting of all kinds, and especially wool carpeting, and composite marble tile exhibit the greatest impacts. No flooring alternative outperforms all others in every impact category.

Key Findings Regarding Impacts of Flooring Choices

Environmental impacts of floor coverings can be minimized by:

- Selecting products made of natural materials that come from plants, such as wood, cork, or linoleum[1] flooring.

  The raw materials for each of these materials are produced by growing plants which, using sunlight as a source of energy, capture carbon dioxide and release oxygen during the growth process, and store captured carbon within the plant material formed. Subsequent conversion of the material into useful products such as flooring typically requires relatively little additional energy, and yields products in which a large proportion of mass consists of stored carbon.

- Giving preference to vinyl or tile with recycled content over products that incorporate a significant synthetic resin content (such as composite marble).

- Avoiding carpet, and wool carpet in particular

  Perhaps surprisingly, wool, a natural product, ranks at the very bottom of virtually every listing of environmentally friendly flooring products. The reason is again linked to carbon, but in this case the low environmental ranking of wool is largely due to very substantial methane emissions from sheep as they digest plant material (cattle and other ruminants have the same problem).

[1] Linoleum is composed of linseed oil obtained from flax seeds, tree resins, various natural materials such as jute, cork, and wood flours, and limestone.

Background

The product comparisons discussed in this report are based on life cycle assessments (LCAs) conducted by various organizations. Data used as a basis for these assessments have been collected and analyzed following a set of internationally recognized rules, resulting in analyses that can be reproduced and verified. Environmental impacts resulting from product production, transportation, installation, use, and ultimate disposal are assessed. A wide range of environmental impact categories are examined.

This is an update of a 2009 report which compared environmental performance of various flooring materials.[2] As in the previous report, the primary source of information on which this report is based is the National Institute of Standards and Technology (NIST). A number of published assessments performed by various research organizations have also informed this report.

The Building for Energy and Environmental Sustainability (BEES) program of NIST is the most comprehensive source of life cycle assessment-based information about building materials in North America. There are currently 46 floor covering products in the system, of which about one-third are distinctly different products. The BEES program is accessible online[3] and free to download and use.

Unfortunately, the range of floor coverings currently included within BEES is limited to those typically used in commercial buildings and institutions. Consequently, products commonly installed in homes, such as hardwood flooring and carpeting with pad are not currently included in the BEES database. Several assessments referenced herein have included wood flooring in comparisons of various other types of floor coverings, and these are reported herein. A search of published information found no LCAs that have examined carpeting systems which include pad, and none which have assessed bamboo flooring from a life cycle perspective. Several previous Dovetail reports have examined environmental aspects of bamboo flooring,[4] but not in the context of an LCA.

Summary of Published Research

National Institute of Science and Technology

Using BEES yields information regarding twelve environmental attributes, including:

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

[2] http://www.dovetailinc.org/report_pdfs/2009/dovetailfloors0809.pdf

[3] BEES online can be accessed via: (https://ws680.nist.gov/bees/(A(AWd6EkyX1AEkAAAAZmFkY2NkMDYtOTBhNS00NjUyLTkwYTAtNGFkYmU4MGUyMjI2v5HcbiJhBZS-lKabIDEl0Kgn44g1))/default.aspx)

[4] http://www.dovetailinc.org/report_pdfs/2005/dovetailbamboo0305.pdf

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. Users may also specify customized weighting factors. This report assesses nine different floor covering products, as described in Table 1.

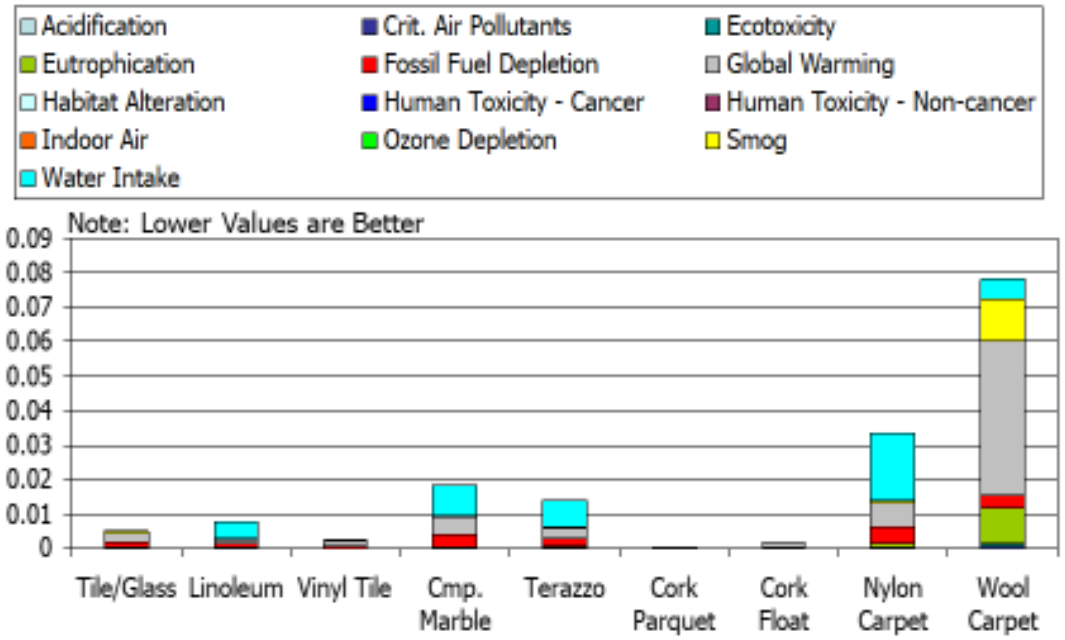
Table 1
Descriptions of the Various Floor Coverings Assessed in the BEES Program

Floor covering material	Product description	Principal raw materials	Est. service life
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.
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.
Natural cork parquet tile	Natural cork sheet made of recovered cork powder generated in making cork bottle stoppers and urethane binder.	Recovered 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.	Recovered 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.
Terrazzo	Terrazzo 0.375 inch thick (9.5 mm) 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.
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.
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.
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 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[5]. When interpreting the impacts, note that lower values are better. Results, based on evaluation of LCA results by both the BEES Stakeholder Panel and the Scientific Advisory Panel of the EPA, show the same ranking of flooring products evaluated (Table 2).

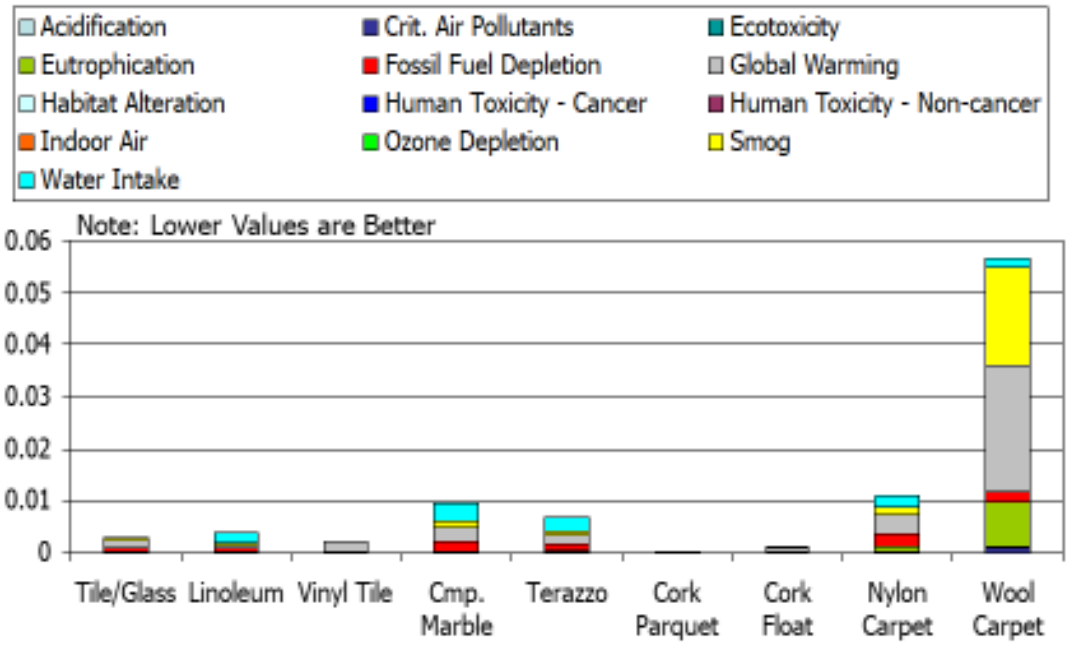
Figure 1
Environmental Performance of Various Floor Covering Options
(Weighting of Environmental Performance Measures by BEES Stakeholder Panel)



Source: BEES 4.0, National Institute of Standards and Technology (2011)

[5] Wood is not evaluated within the BEES environmental impact calculator, and therefore is not included in any of these figures or tables.

Figure 2
Environmental Performance of Various Floor Covering Options
(Weighting of Environmental Performance Measures by EPA Scientific Advisory Panel)



Source: BEES 4.0, National Institute of Standards and Technology (2011)

Rankings of the importance of various environmental performance measures by a BEES expert panel and an EPA scientific advisory panel, though slightly different, resulted in the same rankings of overall environmental impact (Table 2). The product associated with the greatest environmental impact, and by a substantial margin, is wool carpet. Nylon carpet, ranked second worst in environmental performance, in part because of short service life, but was found to have only about one-fourth the magnitude of negative impact as wool. Both of the carpeting systems evaluated in BEES are commercial systems installed without a pad (glued to a concrete floor).[6]

Table 2
A Comparison of Environmental Performance
Rankings Using Various Weighting Factors

	NIST - BEES	
Flooring Product	EPA Science Advisory Board	BEES Stakeholder Panel
Natural cork parquet tile	1 (best)	1
Natural cork floating floor plank	2	2
Vinyl tile	3	3
Ceramic tile with recycled glass	4	4
Linoleum	5	5
Terrazzo	6	6
Composite marble tile	7	7
Nylon broadloom carpet (commercial)	8	8
Wool broadloom carpet (commercial)	9 (worst)	9

[6] The addition of a pad might or might not increase environmental impact. On the one hand, more raw materials and manufacturing would be needed for production of the pad. However, use of a pad can increase carpet life.

While cork and vinyl flooring exhibit the lowest impacts by either ranking system employed by BEES, the impacts linked to ceramic tile with recycled glass and linoleum are not substantially greater. But there are significant differences between the five materials exhibiting the lowest impacts and the next two products – terrazzo and composite marble, and large differences as well between these products and carpeting.

Published Research

Perkins + Will architects studied alternative flooring products used in commercial buildings and institutions, publishing a report in 2010. This assessment, examined vinyl composition tile (VCT), linoleum, nylon carpet tile, ceramic tile, terrazzo, cork, and rubber. Neither wool carpet nor wood flooring were evaluated in this study. Data for all of the products, with the exception of rubber, was obtained from BEES software. Various impact indicators were weighted in accordance with EPA recommendations. Findings indicated the lowest impact floor coverings of those studied to be cork, linoleum, and rubber. Marble, ceramic tile, and nylon carpet ranked as the highest impact flooring products. It was noted that impacts linked to routine cleaning and maintenance can be significant, although these were not evaluated in this study.

Another comparative LCA of alternative flooring products was conducted by Canada's national forest products research organization – FP Innovations. Hardwood flooring was among the products studied. Also assessed were nylon broadloom carpet (no pad), ceramic tile, vinyl, and linoleum. Analysis included impacts from raw material extraction, manufacturing, installation, and disposal. It was assumed that all flooring would be installed over a concrete subfloor, various flooring types would have wear lives as shown in Table 3, and that cork and wood flooring would be burned with energy recovery at end of useful life. Impact categories examined included global warming potential, acidification, eutrophication, smog, ozone depletion, total energy, and fossil-fuel energy. Service life estimates used were based on data obtained from BEES and warranties provided by major flooring manufacturers. Flooring wear life data from several regions of the U.S., from other LCA studies, and from consumer awareness websites were also used in assessing the impact of wear life variability on life cycle impacts.

Table 3
Assumed Service Life of Flooring Products in FP Innovations Study

	Service Life in Years		
Flooring Type	Base Case	Alternative Wear Lives *	Wear life chosen for sensitivity analysis
Hardwood	25	25-100	50
Nylon broadloom carpet	11	5-15	15
Ceramic tiles	50	25-30	30
Vinyl composition tile	40	15	15
Cork	25	30-40	40
Linoleum	30	20	20

* Values based on flooring wear life data from several regions of the U.S., from other LCA studies, and from consumer awareness websites.

Regardless of the wear life assumed, carpet was found to have the greatest impacts for all impact categories due to heavy use of fossil fuels. No single product exhibited the lowest impact in all categories. Vinyl composite tile resulted in the lowest impact with respect to acidification, eutrophication, smog potential, total energy, and fossil fuel energy in the base case assessment, while hardwood flooring was lowest in global warming potential and ozone depletion. When alternative wear lives were used in analyses (far right column of Table 3), with the life of vinyl flooring estimated to be much shorter than in the base case, reflecting common practice, results showed much the same relative impacts, although wood flooring now ranked lowest in fossil energy consumption.

When weighting factors were applied to impact indicators (as determined by the BEES stakeholder panel and EPA advisory panel and as applied in the BEES system), the relative overall ranking of flooring systems showed vinyl composition tile to have the lowest impact, followed by wood, linoleum, cork, ceramic, and carpet. Wood and cork had the lowest global warming potential of the flooring materials examined.

One of the more comprehensive life cycle examinations of flooring options was a study conducted at the Chalmers University of Technology. That study examined the life cycle environmental impacts of three flooring materials: linoleum, vinyl, and solid wood (pine) flooring. Though not common in the U.S., pine and spruce floors are common in Scandinavia. 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 showed solid wood flooring to have a substantially lower impact than the other two flooring types studied (Table 4). 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 4
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).

A number of LCAs of flooring have been conducted in Europe. A 1995 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, compared environmental impacts including depletion of raw materials, embodied energy, global warming, acidification, tropospheric ozone creation, stratospheric ozone depletion, eutrophication, 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 1999 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.

A pair of Canadian studies in the early 2000s compared greenhouse gas (GHG) emissions associated with production and use of wood and other floor coverings. The first study compared solid oak flooring and natural stone, finding that the oak flooring resulted in greater energy use (1.6 times than 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).

Table 5 summarizes findings from all of the life cycle assessment research reported herein. Results consistently show floor coverings made from plant-based materials (wood, cork, linoleum) to have significantly lower global warming potential, and generally lower impact overall than other options. Similarly, carpeting – and particularly wool carpeting – is consistently found to have the greatest global warming potential. Wood, cork, and linoleum similarly exhibit low environmental impact over a wide range of impact measures with, perhaps surprisingly, vinyl also exhibiting low impact.

Table 5
Ranking of Various Floor Covering Materials
Considering a Wide Range of Impact Indicators

Relative Impact	Relative Environmental Ranking	
	Global Warming Potential (Least impact to greatest impact)	Weighted Ranking of All Impact Indicators (Least impact to greatest impact)
Least	Wood	Wood
↓	Natural cork	Natural cork
↓	Natural cork floating floor	Natural cork floating floor
↓	Linoleum	Vinyl composite tile
↓	Vinyl composite tile	Linoleum
↓	Ceramic tile	Ceramic tile
↓	Terrazzo	Terrazzo
↓	Composite marble tile	Composite marble tile
↓	Nylon carpet	Nylon carpet
Greatest	Wool carpet	Wool carpet

Summary

Some flooring products trigger vastly greater environmental impacts than others. No flooring alternative outperforms all others in every impact category. However, systematic assessment of a wide range of impact categories shows plant-based flooring products such as wood and cork to be those generally associated with the lowest impacts, and carpeting and marble floor tiles triggering the greatest impacts. Though a natural material, wool, when used as a floor covering material, has by far the greatest environmental impact of any flooring alternative, including all other types of carpeting material.

The Building for Energy and Environmental Sustainability (BEES) program of NIST is the most comprehensive source of life cycle assessment-based information about building materials in North America, including floor covering alternatives. The program is available on-line and accessible free of charge. Over 45 flooring products, ranging from generic products to brand-name specific products are included in the database as of this date.

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