BEES

Building for Environmental and Economic Sustainability

Balancing Environmental and Economic Performance

by Barbara C. Lippiatt

ADDITIONAL INFORMATION

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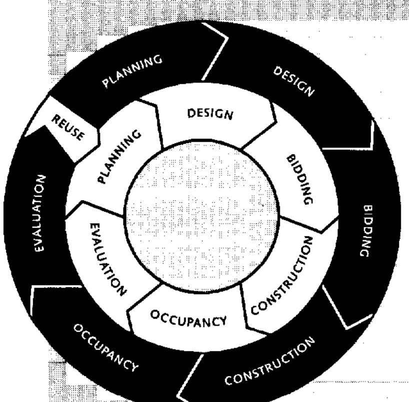
Abstract

Identifying environmentally and economically balanced building products is no easy task. The National Institute of Standards and Technology Green Buildings Program began the Building for Environmental and Economic Sustainability (BEES) project in 1995 to facilitate the identification process. BEES is a systematic methodology implemented in decision support software for selecting building products that achieve the most appropriate balance between environmental and economic performance.



Buildings significantly alter the environment. According to Worldwatch Institute, building construction consumes 40 percent of the raw stone, gravel, and sand used globally each year and 25 percent of the virgin wood.[1] Buildings also account for 40 percent of the energy and 16 percent of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage. Finally, unhealthy indoor air is found in 30 percent of new and renovated buildings worldwide.

Negative environmental impacts arise from these activities. For example, raw materials extraction can lead to resource depletion and biological diversity losses. Building product manufacture and transport consumes energy, the generation of which produces emissions linked to global warming, acid rain, and smog. Landfill problems arise from waste generation, and all these activities lead to air and water pollution. Poor indoor air quality adversely affects human health and lowers worker productivity.

Selecting environmentally preferable building products is one way to improve a building's environmental performance. However, while 93 percent of U.S. consumers worry about their home's environmental impact, only 18 percent are willing to pay more to reduce the impact, according to a survey of 3,600 consumers in nine U.S. metropolitan areas.[2]

Even the most environmentally conscious building designer or product manufacturer will ultimately weigh environmental benefits against economic costs. To satisfy their customers, manufacturers and designers must develop and select building products with an attractive environmental and economic performance balance.

Identifying environmentally and economically balanced building products is not easy. The green building decision-making process is based on little structure and even less credible, scientific data. There is a great deal of interesting green building information available, so that in many respects we know what to *say* about green buildings. However, we still do not know how to synthesize the available information so that we know what to *do* in a way that is transparent, defensible, and truly environmentally sound.

In this spirit, the National Institute of Standards and Technology (NIST) Green Buildings Program began the Building for Environmental and Economic Sustainability (BEES) project in 1995. The purpose of BEES is to develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance. The methodology is based on consensus standards and is practical, flexible, consistent, and transparent. The BEES model is implemented in publicly available decision-support software, the first version of which is available and contains actual environmental and economic performance data for 24 building products. The goal is lowered building-related contributions to environmental problems at minimum cost.

In 1997, the U.S. Environmental Protection Agency (EPA) Environmentally Preferable Purchasing (EPP) Program began supporting the development of BEES. The EPP program is charged with carrying out Executive Order 12873 (10/93), "Federal Acquisition, Recycling, and Waste Prevention," which directs Executive agencies to reduce the environmental burdens associated with the $200 billion in products and services they purchase each year, including building products. Over the next four years, BEES will be further developed to assist the federal procurement community in carrying out Executive Order 12873.

The BEES Methodology

The BEES methodology takes a life-cycle approach (i.e., environmental and economic impacts over a building product's entire life are considered), since product selection decisions based on impacts for a single stage in the life cycle might on the whole prove unsound. For example, lowest first cost does not guarantee lowest life-cycle cost. Alternatively, low environmental impacts during one stage in the environmental life cycle of a product do not guarantee low environmental impacts across all life-cycle stages. A life-cycle approach provides a more comprehensive, balanced analysis.

It is relatively straightforward to select products based on minimum life-cycle economic impacts. But how do we include life-cycle environmental impacts in our purchase decisions? Environmental impacts such as global warming, water pollution, and resource depletion are mostly economic externalities (i.e., their costs are not reflected in the market prices of the products that generated the impacts). It is nearly impossible to include environmental "costs" in market prices, due to difficulties in assessing these impacts in economic terms. How do you put a price on clean air and water? What is the value of human life? Economists have debated these questions for decades, and consensus does not appear likely.

While environmental performance cannot be measured on a monetary scale, it can be quantified using the evolving, multidisciplinary approach known as environmental life-cycle assessment (LCA) (see story, page 49). The BEES methodology measures environmental performance using an LCA approach, following guidance in the ISO 14040 series of draft standards for LCA. Economic performance is separately measured using the ASTM standard life-cycle costing (LCC) approach (ASTM E 917). These two performance measures are then synthesized into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis (MADA) (ASTM E 1765). For the entire BEES analysis, building products are defined and classified according to UNIFORMAT II, the ASTM standard classification for building elements (ASTM E 1557).

Environmental Performance

Environmental LCA is a "cradle-to-grave" systems approach for assessing environmental performance. The approach is based on the belief that all stages in a product's life generate environmental impacts and must therefore be analyzed, including raw materials extraction and processing, product manufacture, transportation, installation, operation and maintenance, and ultimately recycling and waste management.

The strength of environmental LCA is its comprehensive, multidimensional scope. Many green building claims and strategies are based on a single life-cycle stage or environmental impact. A product is called green simply because it has recycled content, or said not to be green because it emits volatile organic compounds (VOCs) during its installation and use. These single-attribute claims ignore the possibility that other life-cycle stages, or other attributes, may yield offsetting impacts. For example, the recycled-content product may have a high embodied energy content, leading to resource depletion, global warming, and acid rain impacts during the raw materials extraction and manufacturing life-cycle stages.

LCA accounts for shifts of environmental problems from one life-cycle stage to another or one environmental medium (land, air, water) to another. LCA uses a trade-off analysis to achieve a genuine reduction in overall environmental impact, rather than a simple shift of impact.

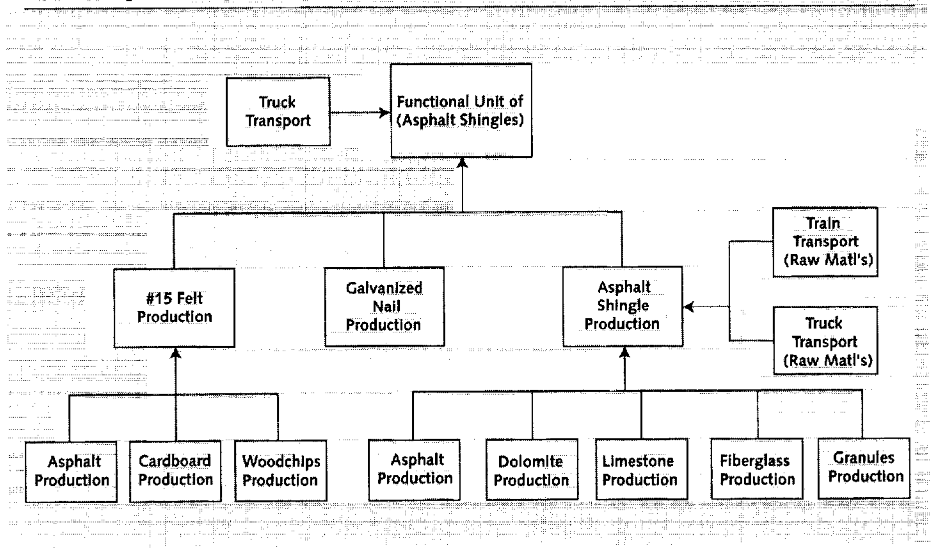
The general LCA methodology involves four steps.[3] *Goal and scope definition* spells out the study's purpose, breadth, and depth. *Inventory analysis* identifies and quantifies environmental inputs and outputs (or inventory flows) associated with a product over its entire life cycle. Environmental inputs include water, energy, land, and other resources; outputs include releases to air, land, and water. *Impact assessment* characterizes these inventory flows in relation to a set of environmental impacts. For example, the impact assessment step might relate carbon dioxide emissions, a flow, to global warming, an impact. Finally, *interpretation* combines the environmental impacts in accordance with the goals of the LCA study.

1. Goal and Scope Definition. The goal of the BEES LCA is to generate relative environmental scores for building product alternatives based on U.S. average data. These scores are combined with relative, U.S. average economic scores to provide guidance to the building community for selecting environmentally and economically balanced building products.

The scoping phase involves defining the boundaries of the product systems under study. The manufacture of any product involves several unit processes. Each unit process involves many inventory flows, some of which involve other, subsidiary unit processes.

Which of these unit processes should be included in the LCA? In the BEES system, the boundary-setting rule consists of a set of decision criteria. For each candidate unit process, mass and energy contributions to the product system are the primary decision criteria. In some cases, cost contribution is used for further decision support.[4] Together, these decision criteria provide a robust screening process for setting product system boundaries. *Figure A*, page 37, shows the processes

Figure A Asphalt shingle unit processes



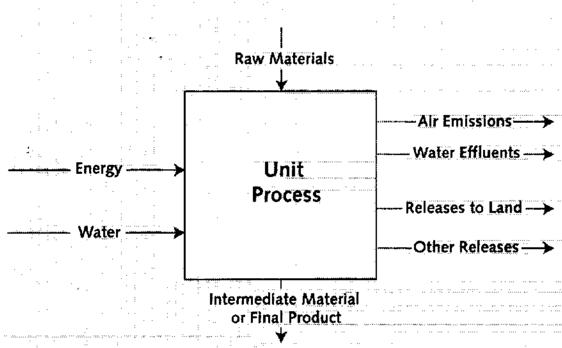
FIGURES COURTESY NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY included in the BEES system for asphalt shingle roof covering.

Defining the unit of comparison, or functional unit, is another important task in the goal and scoping phase of LCA. To compare products, units must be defined so that the products are true substitutes for one another. In the BEES model, the functional unit for most building products is 0.09 m^2 (1 ft^2) of product for 50 years.[5] For example, the functional unit for the BEES roof covering alternatives is *covering 0.09 m^2 (1 ft^2) of roof surface for 50 years.* The functional unit provides the critical reference point to which all inventory flows are scaled.

Scoping also involves setting data requirements. Data requirements for the BEES study include:

- Geographic coverage. The data is U.S. average data.

Figure B BEES inventory data categories



- Time period covered. The data is a combination of data collected specifically for the BEES system within the last 18 months and data from the well-known Ecobalance LCA database created in 1990.[6] Most of the Ecobalance data is updated annually. No data older than 1990 is used.
- Technology covered. Where possible, the most representative technology is studied; otherwise, an aggregated result is used based on the U.S. average technology for that industry.

The purpose of BEES is to develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance.

2. Inventory Analysis. Inventory analysis quantifies the inventory flows for a product system. *Figure B* shows the categories under which data is grouped in the BEES system.

Several approaches may be used to collect inventory data for LCAs. Since the goal of the BEES LCA is to generate U.S. average results, data is primarily collected using the industry-average approach, where data is derived from a representative sample of locations believed to statistically describe the typical process across technologies. Data collection is done under contract with Environmental Strategies and Solutions, Inc. (ESS) and Ecobalance, Inc., using the Ecobalance LCA database covering more than 6,000 industrial processes gathered from actual site and literature searches from more than 15 countries. Where necessary, the data is adjusted to be representative of U.S. operations and conditions.

Approximately 90 percent of the data comes directly from industry sources, with about 10 percent coming from literature and published reports. The latter includes inventory flows for electricity production from the average U.S. grid and for selected raw material mining operations (e.g., limestone, sand, and clay). ESS and Ecobalance gathered additional LCA information to fill data gaps for the BEES products. Assumptions regarding the unit processes for each building product were verified through experts in the appropriate industries.

3. Impact Assessment. The impact assessment step of LCA quantifies the potential contribution of a product's inventory flows to a range of environmental impacts. There are several well-known LCA impact assessment approaches. The primary approach used in the BEES impact assessment is the classification/characterization approach.

The classification/characterization approach was developed within the Society for Environmental Toxicology and Chemistry (SETAC) and involves a two-step process:[7] 1) classification of inventory flows that contribute to specific environmental impacts (for example, greenhouse gases such as carbon dioxide, methane, and nitrous oxide are classified as contributing to global warming) and 2) characterization of the potential contribution of each classified inventory flow to the corresponding environmental impact. This results in a set of indices, one for each impact, that is obtained by weighting

Table 1 Hypothetical BEES impact assessment results

Impact Category	Units	Product A	Product B
Global Warming	carbon dioxide equivalents (kg/funct. unit[a])	610	1123
Acidification	hydrogen equivalents (kg/funct. unit)	0.250	0.207
Nutrification	phosphate equivalents (kg/funct. unit)	0.430	0.827
Natural Resource Depletion	resource depletion factor (per funct. unit)	0.006	0.050
Indoor Air Quality	dimensionless score	0.05	0.45
Solid Waste	volume to landfill (yd^3/ funct. unit)	3.407	2.688

[a]Functional unit is 0.09 m^2 (1 ft^2) of product for 50 years

Table 2 Relative importance weights based on Science Advisory Board and Harvard studies

Impact Category	Relative Importance SAB	Weights (%) Harvard
Global Warming	27	28
Acidification	13	17
Nutrification	13	18
Natural Resource Depletion	13	15
Indoor Air Quality	27	12
Solid Waste	7	10

each classified inventory flow by its relative contribution to the impact. For instance, the Global Warming Potential index is derived by expressing each contributing inventory flow in terms of its equivalent amount of carbon dioxide.

This classification/characterization method does not offer the same degree of relevance for all environmental impacts. For global and regional effects (e.g., global warming and acidification), the method may result in an accurate description of the potential impact. For impacts dependent on local conditions (e.g., smog), it may result in an oversimplification of the actual impacts because the indices are not tailored to localities.

For this reason and because BEES has a U.S. average scope, local impacts such as smog are not included. The following global and regional impacts are assessed using the classification/characterization approach and included in BEES: global warming, acidification, nutrification, and natural resource depletion. Indoor air quality and solid waste impacts are also included in BEES, for a total of six impacts. Besides local impacts, other potential environmental impacts are not included. For example, ozone depletion, though an important global impact that has been successfully classified and characterized, is excluded. The primary inventory flows that contribute to ozone depletion (chlorofluorocarbons, halons, and chlorine-based solvents) are being phased out. Thus, inventory flow data is quickly changing, and soon there will be little left to report.

Human health impacts are also not explicitly included in the BEES system because the science is not sufficiently developed. If the BEES user has important knowledge about these or other potential environmental impacts, it should be brought into the interpretation of the BEES results.

Table 1 illustrates BEES impact assessment results for two hypothetical product alternatives.

4. *Interpretation.* At the LCA interpretation step, the impact assessment results are combined. Few products are likely to dominate competing products in all six BEES impact categories. Rather, one product may outperform the competition relative to natural resource depletion and solid waste, fall short relative to global warming and acidification, and fall somewhere in the middle relative to indoor air quality and nutrification.

Synthesizing the six impact category performance measures involves combining apples and oranges. Global warming potential is expressed in carbon dioxide equivalents, acidification in hydrogen equivalents, nutrification in phosphate equivalents, natural resource depletion as a factor reflecting remaining years of use and reserve size, solid waste in volume to landfill, and indoor air quality as a dimensionless score.

MADA can be used to combine the diverse measures of impact category performance into a meaningful measure of overall environmental performance. MADA problems are characterized by tradeoffs between apples and oranges, as is the case with the BEES impact assessment results. The BEES system follows the ASTM standard for conducting MADA evaluations of building-related investments.[8]

MADA first places all impact categories on the same scale by normalizing them. Within an impact category, each product's performance measure is normalized by dividing by the highest measure for that category. All performance measures are thus translated to the same dimensionless, relative scale from 0 to 100, with the worst performing product in each category assigned a normalized score of 100.

MADA then weights each impact category by its relative importance to overall performance. In the BEES software, the set of importance weights is defined by the user. Several derived, alternative weight sets are provided as guidance. These alternative weight sets are based on an EPA Science Advisory Board study, a Harvard University study, and a set of equal weights. The alternative sets of weights represent

Table 3 Deriving BEES environmental performance scores

	Product A		Product B	
Impact Category	**Normalized Impact Assessment Score**	**Normalized, Weighted Impact Assessment Score**	**Normalized Impact Assessment Score**	**Normalized, Weighted Impact Assessment Score**
Global Warming	54	15	100	28
Acidification	100	17	83	14
Nutrification	52	9	100	18
Natural Resource Depletion	12	2	100	15
Indoor Air Quality	11	1	100	12
Solid Waste	100	10	79	8
	Environmental Performance Score: 54		Environmental Performance Score: 95	

a spectrum of ways in which people, including the experts, value various aspects of the environment.

In 1990, the EPA Science Advisory Board (SAB) developed lists of the relative importance of various environmental impacts to help EPA best allocate its resources. The following criteria were used to develop the lists:

- spatial scale of the impact
- severity of the hazard
- degree of exposure
- penalty for being wrong.

Five of the BEES impact categories were among the SAB lists of relative importance:[9]

- Relatively High-Risk Problems: global warming, indoor air quality
- Relatively Medium-Risk Problems: acidification, nutrification
- Relatively Low-Risk Problems: solid waste.[10]

The SAB did not explicitly consider natural resource depletion an impact. For this exercise, natural resource depletion is assumed to be a relatively medium-risk problem, based on other relative importance lists.[11]

Verbal importance, such as "relatively high-risk," may be translated into a numerical importance weight by following guidance provided by MADA.[12] The second column of *Table 2*, page 39, shows the importance weights derived for the six BEES impacts based on the verbal rankings from the SAB study.

In 1992, an extensive study was conducted at Harvard University to establish the relative importance of environmental impacts.[13] The study developed separate assessments for the United States, The Netherlands, India, and Kenya. In addition, separate assessments were made for "current consequences" and "future consequences" in each country. For current consequences, more importance is placed on impacts of prime concern today. Future consequences places more importance on impacts that are expected to become significantly worse in the next 25 years. Five of the BEES impact categories were among the studied impacts. The study did not explicitly consider solid waste an impact. For this exercise, solid waste is assumed to rank low for both current and future consequences, based on other relative importance lists.[14]

As with the SAB study, verbal importance rankings specified in the Harvard study may be translated into numerical, relative importance weights by following guidance provided by MADA. Sets of relative importance weights are derived for current and future consequences and then combined by weighting future consequences as twice as important as current consequences.[15]

Table 2, column 3, lists the combined relative importance weights for the six BEES impacts based on the Harvard study. This set of combined importance weights is offered as an option in BEES. *Table 3* illustrates how the *Table 1* impact assessment results are synthesized into environmental performance scores using the relative importance weights based on the Harvard University study.

Economic Performance

To assess economic performance, published economic performance data is readily available, and there are ASTM standard methods for conducting economic performance evaluations. Cost data is collected for the BEES system from the R.S. Means publication, *1997 Building Construction Cost Data*, and future cost data is based on data published by Whitestone Research

Table 4 Deriving BEES economic performance scores

Economic Performance Measure	Product A	Product B
First Cost ($/funct. unit[a])	1.20	1.40
Future Costs (Present Value $/funct. unit)	3.80	0.60
Life-Cycle Cost ($/funct. unit)	5.00	2.00
Economic Performance Score	**100**	**40**

[a]Functional unit is 0.09 m^2 (1 ft^2) of product for 50 years

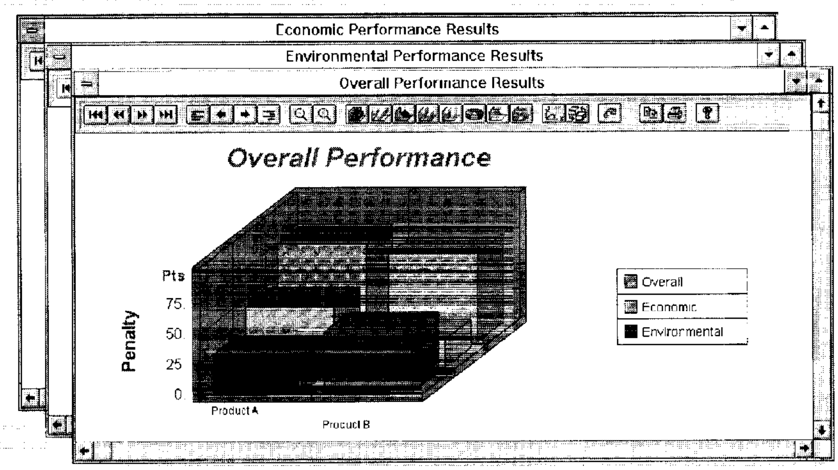
in *The Whitestone Building Maintenance and Repair Cost Reference 1997*, supplemented by industry interviews. The most appropriate method for measuring the economic performance of building products is the life-cycle cost (LCC) method. Thus, the BEES system follows the ASTM standard method for LCC of building-related investments.[16]

Unlike the environmental life cycle, the economic life cycle is limited to a fixed period (known as the study period) beginning with the purchase and installation of the product and ending at some point in the future that does not necessarily correspond with product end-of-life. Economic performance is evaluated beginning at product purchase and installation because this is when out-of-pocket costs begin to be incurred, and investment decisions are made based on out-of-pocket costs. The economic life cycle ends at a fixed date. Its length is often set at the useful life of the longest-lived product alternative. However, when all alternatives have very long lives (e.g., more than 50 years), a shorter study period may be selected for three reasons:

- Technological obsolescence becomes an issue.
- Data becomes too uncertain.
- The further in the future, the less important the costs.

In the BEES model, economic performance is measured over a 50-year study period. The same 50-year period is used to evaluate all products, even if they have different useful lives. For consistency, the BEES model evaluates the use stage of environmental performance over the same 50-year study period. Product replacements over this 50-year period are accounted for in the environmental performance score.

Figure C BEES overall performance scores



In the BEES model, ECONOMIC performance is measured over a 50-year study period. The same 50-year period is used to evaluate all products, even if they have different useful lives.

The LCC method totals all relevant costs associated with a product over the study period. Alternative products for the same function, say floor covering, can then be compared on the basis of their LCCs to determine which is the least expensive means of providing that function over the study period. Categories of cost typically include purchase, installation, maintenance, repair, and replacement.

A negative cost item is the residual value. The residual value is the product value remaining at the end of the study period. In the BEES model, the residual value is computed by prorating the purchase and installation cost over the product life remaining beyond the 50-year period.[17]

The LCC method accounts for the time value of money by using a discount rate to convert all future costs to their equivalent present value. The BEES model computes LCCs using constant 1997 dollars and a real discount rate. As a default, the BEES system uses a real discount rate of 3.6 percent, the 1997 rate mandated by the U.S. Office of Management and Budget for most federal projects.[18]

Overall Performance

The BEES overall performance score combines the environmental and economic results. To combine them, the two results must first be placed on a common basis. The environmental performance score reflects *relative* environmental performance, or how much better or worse products perform with respect to one another. The life-cycle cost reflects *absolute* performance, irrespective of the alternatives under analysis. Before combining the two, the life-cycle cost is converted to the same relative basis as the environmental score, as shown in *Table 4*. Then, the two performance scores are combined into a relative, overall score by weighting environmental and economic performance by their relative importance values.

Figure C, page 41, illustrates the display of overall performance results in the BEES system using the performance scores from *Tables 3* and *4*, page 40, and based on an equal weighting of environmental and economic performance. The graph displays each product's weighted environmental and economic performance scores and their sum, the overall performance score. Note that the more penalty points, the *worse* the performance.

The BEES user specifies the relative importance weights used to combine environmental and economic performance scores, and should test the sensitivity of the overall scores to different sets of relative importance weights.

Future Directions

Over the next several years, BEES will be expanded and refined. Product technical performance will be added to the overall environmental/economic balance, and sensitivity analysis for testing the effect of changes in key study parameters will be automated. U.S. region specificity and greater flexibility in product specifications (e.g., useful lives) will also be incorporated. Finally, many more products will be added to the system so that entire building components and systems can be compared. ■

Notes

1. D.M. Roodman and N. Lenssen, *A Building Revolution: How Ecology and Health Concerns are Transforming Construction*, Worldwatch Paper 124, Worldwatch Institute (Washington, D.C., March 1995).
2. 1995 Home Shoppers survey cited in *Minneapolis Star Tribune* (November 16, 1996): H4 (article by Jim Buchta).
3. International Standards Organization, *Environmental Management—Life-Cycle Assessment—Principles and Framework*, Draft International Standard 14040, 1996.
4. While a high cost does not directly indicate a significant environmental impact, it may indicate scarce natural resources or numerous subsidiary unit processes potentially involving high energy consumption.
5. All product alternatives are assumed to meet minimum technical performance requirements (e.g., acoustic and fire performance).
6. Ecobalance, Inc., *DEAM™: Data for Environmental Analysis and Management* (Rockville, Maryland, 1997).
7. SETAC-Europe, *Life Cycle Assessment*, Eds. B. DeSmet, et al., 1992; SETAC, *A Conceptual Framework for Life Cycle Impact Assessment*. Eds. J. Fava, et al., 1993; and SETAC, *Guidelines for Life Cycle Assessment: A "Code of Practice,"* Eds. F. Consoli, et al., 1993.
8. American Society for Testing and Materials, Standard Practice for Applying the Analytic Hierarchy Process to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems, ASTM E 1765-95 (West Conshohocken, Pennsylvania, 1995).
9. United States Environmental Protection Agency, Science Advisory Board, *Reducing Risk: Setting Priorities and Strategies for Environmental Protection*, SAB-EC-90-021 (Washington, D.C., September 1990): 13-14.
10. The SAB report classifies solid waste under its low-risk groundwater pollution category (SAB, *Reducing Risk*, Appendix A, pp. 10-15).
11. See, for example, Hal Levin, "Best Sustainable Indoor Air Quality Practices in Commercial Buildings," *Third International Green Building Conference and Exposition—1996*, NIST Special Publication 908 (Gaithersburg, Maryland, November 1996): 148.
12. Thomas L. Saaty, *MultiCriteria Decision Making: The Analytic Hierarchy Process—Planning, Priority Setting, Resource Allocation* (University of Pittsburgh, 1988).
13. Vicki Norberg-Bohm et al, *International Comparisons of Environmental Hazards: Development and Evaluation of a Method for Linking Environmental Data with the Strategic Debate Management Priorities for Risk Management*, Center for Science & International Affairs, John F. Kennedy School of Government, Harvard University, October 1992.
14. See, for example, Hal Levin, "Best Sustainable Indoor Air Quality Practices in Commercial Buildings," p. 148. As in the SAB report, solid waste is classified under groundwater pollution.
15. The Harvard study ranks impacts "high" in future consequences if the current level of impact is expected to double in severity over the next 25 years based on a "business as usual" scenario. Vicki Norberg-Bohm, *International Comparisons of Environmental Hazards*, 11-12.
16. American Society for Testing and Materials, Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, ASTM E 917-93 (West Conshohocken, Pennsylvania, March 1993).
17. For example, a product with a 40-year life that costs \$10 per 0.09 m^2 (\$10 per ft^2) to install would have a residual value of \$7.50 in year 50, considering replacement in year 40.
18. Office of Management and Budget (OMB) Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* (Washington, DC, October 27, 1992) and OMB Circular A-94, Appendix C (March 1997).

Ordering Information

The BEES 1.0 software, with environmental and economic performance data for 24 buildling products, may be ordered by contacting the U.S. Green Building Council, 90 New Montgomery Street, Suite 1001, San Francisco, California, 94105; (415) 543-3001, fax (415) 957-5890, e-mail info@usgbc.org. It can also be ordered directly from the Council's Web site at www.usgbc.org.

Editor's Note

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