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Building for Environmental and Economic Sustainability (BEES)

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Abstract

The BEES (**B**uilding for **E**nvironmental and **E**conomic **S**ustainability) software implements a rational, systematic technique for balancing thc environmental and economic performance of building products. The technique is based on consensus standards and designed to be practical, flexible, and transparent. The Windows-based decision support software, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for a number of building products.

BEES measures the environmental performance of building products by using the environmental life-cycle assessment approach specified in the latest versions of ISO 14000 draft standards. The approach is based on the belief that all stages in the life of a product generate environmental impacts and must therefore be analyzed. The stages include raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Economic performance is measured using the American Society for Testing and Materials (ASTM) standard life-cycle cost method. The technique includes the costs over a given study period of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements known as UNIFORMATII.

The BEES methodology is being refined and expanded over the next three years under sponsorship of the U.S. Environmental Protection Agency's Environmentally Preferable Purchasing (EPP) Program. The EPP program is charged with carrying out Executive Order 12873, "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. BEES is being further developed as a tool to assist the Federal procurement community in carrying out the mandate of Executive Order 12873.

Keywords: building products, economic performance, environmental performance, green buildings, life-cycle assessment, life-cycle costing, multiattribute decision analysis, sustainable development

1 Introduction

Buildings significantly alter the environment. According to Worldwatch Institute [1], building construction consumes 40 percent of the raw stone, gravel, and sand used globally each year, and 25 percent of the virgin wood. 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. 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, generating emissions linked to global warming, acid rain, and smog. Landfill problems may arise from waste generation. Poor indoor air quality may lower worker productivity and adversely affect human health.

Thus, building-related contributions to environmental problems are large, and therefore important. 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]. To be practical, then, environmental performance must be balanced against economic performance. Even the most environmentally conscious building designer or building product manufacturer will ultimately weigh environmental benefits against economic costs. To satisfy their customers, manufacturers and designers need to develop and select building products with an attractive balance of environmental and economic performance.

In this spirit, the U.S. National Institute of Standards and Technology (NIST) Green Buildings Program began the **B**uilding for **E**nvironmental and **E**conomic **S**ustainability (BEES) project in 1994. The purpose of the BEES project is to develop and implement a systematic methodology for selecting environmentally and economically balanced building products. The methodology is based on consensus standards and is designed to be practical, flexible, and transparent. The BEES model is being implemented in publicly available decision-support software, complete with actual environmental and economic performance data for a number of building products. The intended result is a cost-effective reduction in building-related contributions to environmental problems.

In 1997, the U.S. Environmental Protection Agency Environmentally Preferable Purchasing (EPP) Program also 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 U.S. 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 several years, BEES will be further developed as a tool to assist the U.S. Federal procurement community in carrying out the mandate of Executive Order 12873.

This paper describes in general terms the current formulation of the BEES model for balancing the environmental and economic performance of building products, and illustrates its application in Windows-based decision support software.

2 Methodology

The BEES methodology takes a multidimensional, life-cycle approach. That is, it considers multiple environmental and economic impacts over the entire life of the building product. Considering multiple impacts is necessary because product selection decisions based on single environmental or economic impacts, such as recylability or first cost, could obscure other impacts that might cause equal or greater damage. Similarly, considering all life-cycle stages is necessary because decisions based on a single stage, such as the use stage, could obscure other stages that might cause equal or greater damage. In other words, a multidimensional, life-cycle approach is necessary for a comprehensive, balanced analysis.

Environmental performance is quantified using the evolving, multi-disciplinary approach known as life-cycle assessment (LCA). The BEES methodology follows guidance in the ISO 14040 series of draft standards for LCA. Economic performance is separately measured using the American Society for Testing and Materials (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 (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). All underlying data and computational algorithms are reported and documented.

2.1 Environmental performance

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

The general LCA methodology involves four steps [3]. The *goal and scope definition* step spells out the purpose of the study and its breadth and depth. The *inventory analysis* step identifies and quantifies the environmental inputs and outputs 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. However, it is not these inputs and outputs, or *inventory flows,* that are of interest. More important are their consequences, or impacts on the environment. Thus, the next LCA step, *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, the *interpretation* step combines the environmental impacts in accordance with the goals of the LCA study. For a detailed discussion of these steps, see Lippiatt [4].

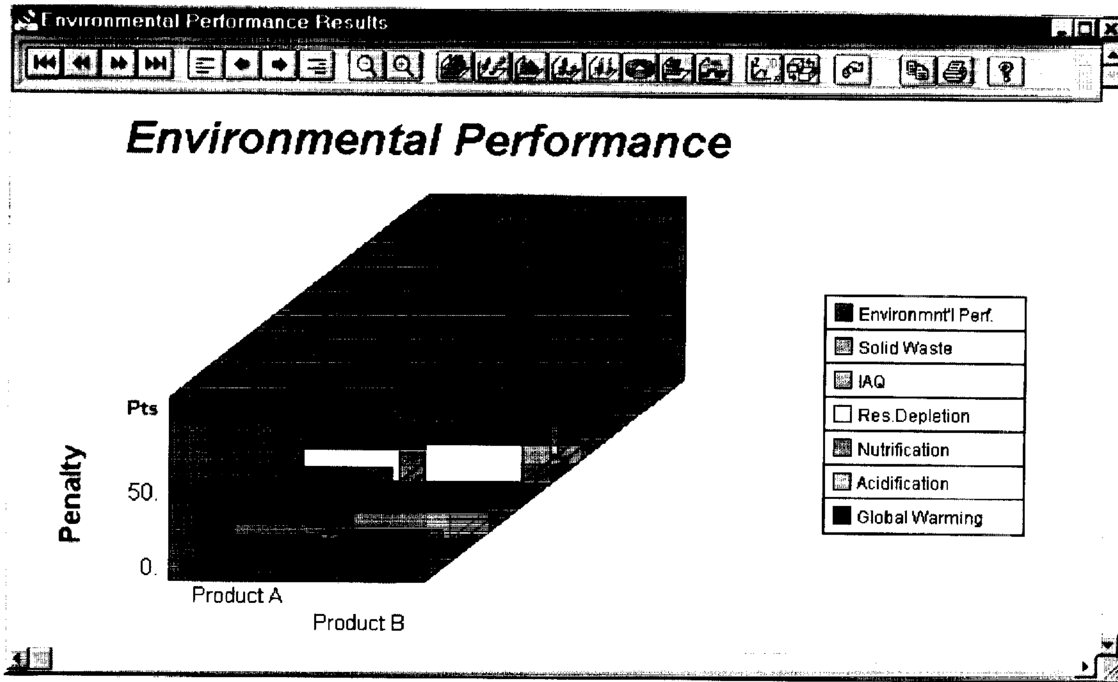

Figure 1. BEES Environmental Performance Results

The goal of the BEES LCA is to generate relative environmental scores for building product alternatives based on U.S. average data. LCA 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 and gathered from actual site and literature searches from more than 15 countries. Where necessary, the data are adjusted to be representative of U.S. operations and conditions. In addition, ESS and Ecobalance gathered additional LCA data to fill data gaps for the BEES products. Assumptions made for each building product were verified through experts in the appropriate industry to assure the data are correctly incorporated in BEES.

The BEES model assesses six environmental impacts: Global Warming Potential, Acidification Potential, Nutrification Potential, Natural Resource Depletion, Indoor Air Quality, and Solid Waste. Because BEES uses U.S. average data, local impacts such as smog could not be included. Human health impacts are also excluded because the science is not yet sufficiently developed. However, 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.

Synthesizing the six impact category performance measures into a single, meaningful measure of overall environmental performance involves combining apples and oranges. BEES expresses global warming potential 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. BEES combines these diverse measures of impact category performance into a meaningful measure of overall environmental performance using Multiattribute Decision Analysis (MADA), a technique for combining apples and oranges. The BEES system follows

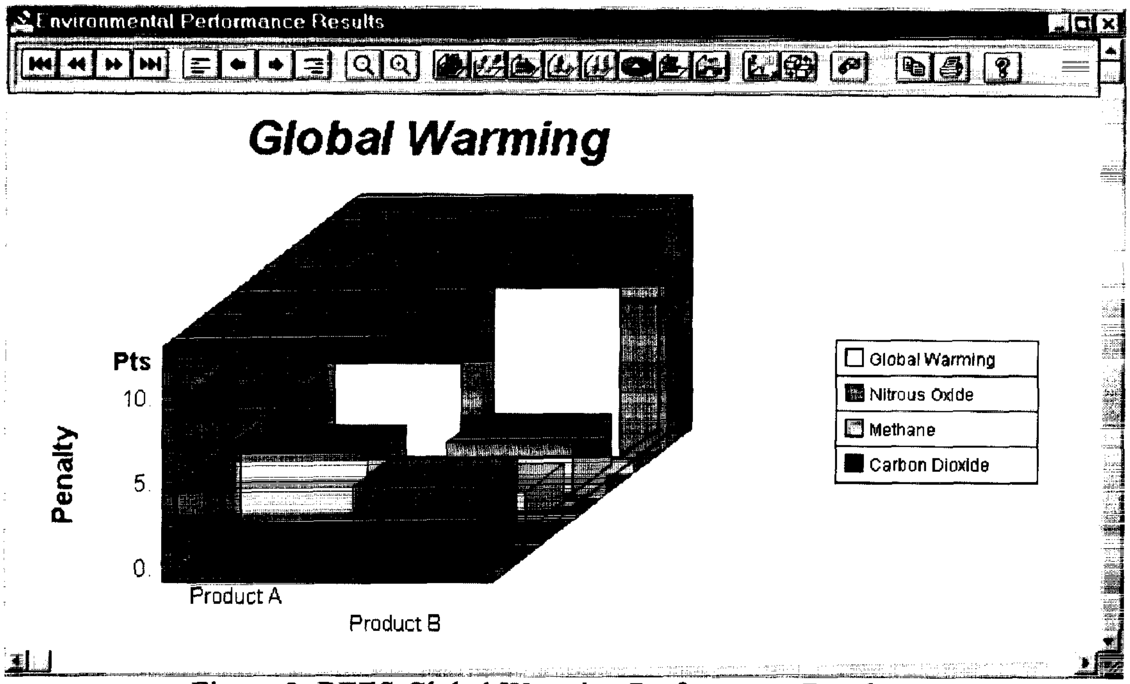

Figure 2. BEES Global Warming Performance Results

the ASTM standard for conducting MADA evaluations of building-related investments. [5]

MADA synthesizes the impact category performance measures by first placing them on a common scale, then weighting each impact category by its relative importance to environmental performance. (For a step-by-step example working through the numerical computations, see Lippiatt [4].) In the BEES software, the set of importance weights is chosen by the user. Two alternative weight sets are provided as guidance. These alternative weight sets are based on studies by the U.S. Environmental Protection Agency's Science Advisory Board and by Harvard University, and represent two different ways in which the United States, including its experts, values the environment. The BEES user may choose to use one of these weight sets unchanged, or as a starting point for developing their own set of weights.

Figure 1 illustrates the BEES graphical display of environmental performance results. The BEES environmental performance scores for Products A and B are displayed across the back row. This score is denominated in penalty points ranging from 0 to 100. As shown, Product B has worse environmental performance than Product A.

For each product, the environmental performance score is the sum of its weighted scores for the six environmental impacts, which are displayed in the remaining rows of the graph. Figure 1 illustrates the tradeoffs among environmental impacts that are often found in LCAs. Product B performs worse than Product A on global warming, acidification, resource depletion, and indoor air quality, better on nutrification, and about the same on solid waste.

The BEES tool also displays detailed graphical results for each of the six environmental impacts. Figure 2 illustrates these results for the global warming impact. The global warming scores from Figure 1 for Products A and B are now

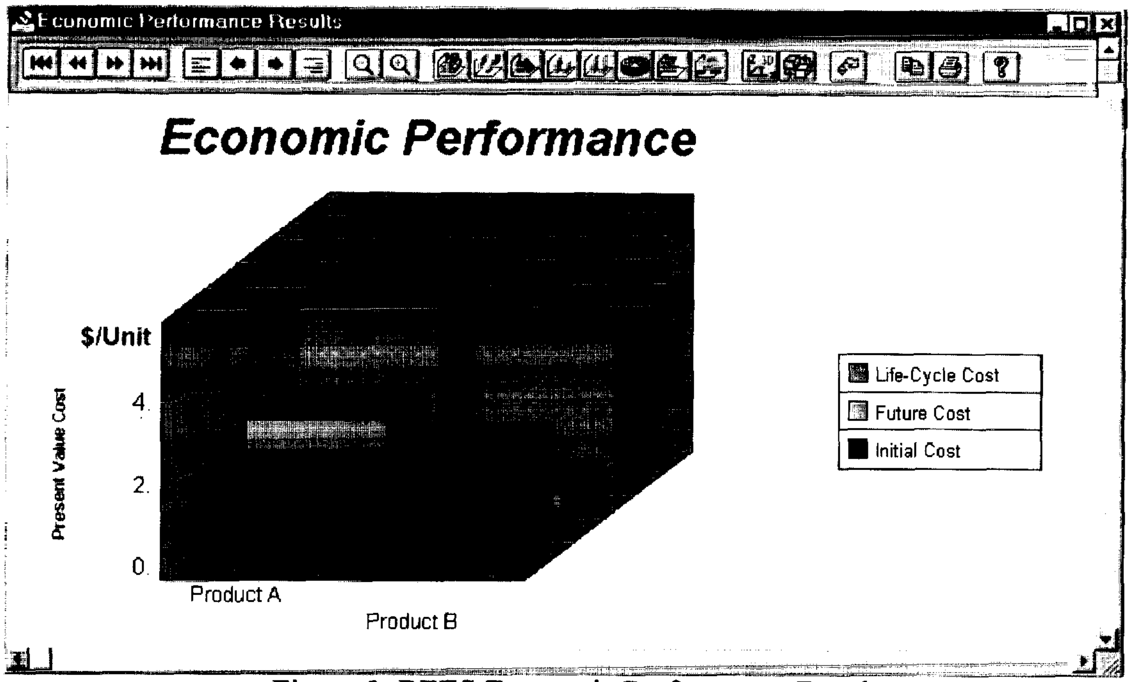

Figure 3. BEES Economic Performance Results

displayed across the back row, with their breakdown among the contributing greenhouse gases in the remaining rows. As shown, the global warming score, which is almost twice as bad for Product B as Product A, is the sum of scores for carbon dioxide, methane, and nitrous oxide.

2.2 Economic performance

Measuring the economic performance of building products is more straightforward than measuring environmental performance. Published economic performance data are readily available, and there are well-established, standard methods for conducting economic performance evaluations. First-cost data are collected for the BEES tool from the R.S. Means publication, *1997 Building Construction Cost Data*, and future-cost data are based on data published by Whitestone Research in *The Whitestone Building Maintenance and Repair Cost Reference 1997.* The most appropriate method for measuring the economic performance of building products is the life-cycle costing (LCC) method. BEES follows the American Society of Testing and Materials standard method for life-cycle costing of building-related investments [6].

BEES measures economic performance over a 50-year study period. The same 50-year period is used to evaluate all products, even if they have different useful lives. Evaluating products over a common time period is one of the strengths of the LCC method. It accounts for the fact that different products have different useful lives.

The LCC method sums over the study period all relevant costs associated with a product. 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-cost means of providing that function over the study period. Categories of cost typically include costs for purchase, installation, maintenance, repair, and replacement. The LCC

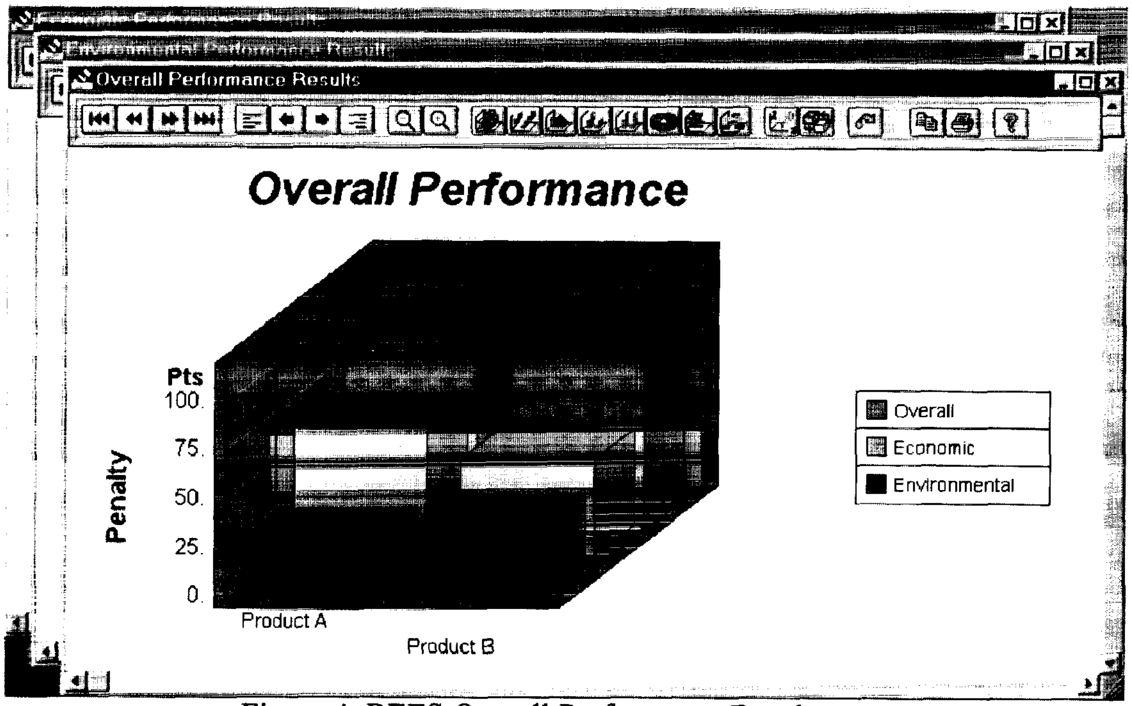

Figure 4. BEES Overall Performance Results

method accounts for the time value of money by using a discount rate to convert all future costs to their equivalent present value.

Figure 3 illustrates the BEES graphical display of economic performance results for two product alternatives. The LCCs for Products A and B are displayed across the back row. As shown, Product A has a higher life-cycle cost than does Product B, even though its initial cost is lower, illustrating the importance of taking a life-cycle view.

2.3 Overall performance

BEES combines the environmental and economic performance results into a single overall performance score. To combine them, the results must first be placed on a common scale. 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 set of alternatives under analysis. Before combining the two, the life-cycle cost is converted to the same, relative scale as the environmental score. Then the two performance scores are combined into a relative, overall score by assigning importance weights to environmental and economic performance. (For a step-by-step example working through the numerical computations, see Lippiatt [4].)

Figure 4 illustrates the BEES display of overall performance results. The environmental and economic performance scores from Figures 1 and 3 have been combined based on a 35 percent/65 percent environmental/economic importance weighting. The graph displays for each product its weighted environmental and economic performance scores and their sum, the overall performance score.

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

3 Discussion and conclusions

Until now, green building decision making has been based on little structure and scientific data. There is a great deal of interesting green building information available, so in many respects we know what to *say* about green buildings. However, we have not organized and synthesized the scientific data so that we know what to *do* in a way that is both environmentally sound and cost effective.

The BEES tool satisfies this need by offering a unique blend of environmental science, decision science, and economics. It uses life-cycle concepts, is based on consensus standards, and is designed to be practical, flexible, and transparent. It is *practical* in its systematic packaging of detailed performance data in a manner that offers useful decision support. It is *flexible* in allowing tool users to customize judgments about key study parameters for which there is no consensus, such as the environmental impact category weights. Finally, it is *transparent* in providing the supporting performance data and computational algorithms.

The BEES tool will be expanded and refined over the next several years. 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.

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