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Life-Cycle Cost Analysis for Buildings Is Easier Than You Thought

Cover figure—The Interagency Helibase in Jackson Hole was built cooperatively by the Bridger-Teton National Forest of the Intermountain Region and Grand Teton National Park.

Life-Cycle Cost Analysis for Buildings Is Easier Than You Thought

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Introduction

Life-cycle cost analysis is a method of determining the entire cost of a structure, product, or component over its expected useful life. The cost of operating, maintaining, and using the item is added to the purchase price. For items that last longer than a couple of years, this is a more realistic way of evaluating cost than simply looking at the purchase price. Conducting a life-cycle cost analysis isn't as difficult as it appears. This report explains why and how to conduct life-cycle cost analyses and includes information on using software tools that reduce the difficulty of performing life-cycle cost analyses.

Don't confuse life-cycle cost analysis with life-cycle assessments. Life-cycle assessments are used to evaluate the environmental costs associated with a product, process, structure, or activity. They identify energy and materials used and wastes released to the environment. Life-cycle assessments are explained in more detail in the "Life-Cycle Assessments Can Help You Make Sustainable Choices" section of this report.

Highlights...

- Life-cycle cost analysis is a structured method of determining the entire cost of a structure, product, or component over its expected useful life.
- Life-cycle cost analysis isn't as difficult as it appears.
- Life-cycle cost analysis can provide Forest Service decisionmakers with the financial information they need to make responsible decisions about maintaining, improving, and constructing facilities.

Life-Cycle Cost Analysis for Forest Service Buildings Is Smart Business

Because funding is limited, Forest Service, U.S. Department of Agriculture, designers and facilities managers traditionally have focused on minimizing the initial cost of a structure. Unfortunately, this practice often has produced inefficient, short-lived structures with unnecessarily high operation and maintenance costs. Over the life of a building, operation and maintenance cost more than initial construction (figure 1). This is true both for new construction and for major replacement and improvement projects, so it makes sense to include operation and maintenance when evaluating cost effectiveness.

The 2006 study "Re-examining the Costs and Value Ratios of Owning and Occupying Buildings" by Graham Ive found the cost of operation and maintenance of office buildings to be about one and a half times the cost of initial construction. Other estimates put the cost of operation and maintenance at up to five times the cost of initial construction. Spending less over the long haul on buildings means you can spend more on the Forest Service mission.

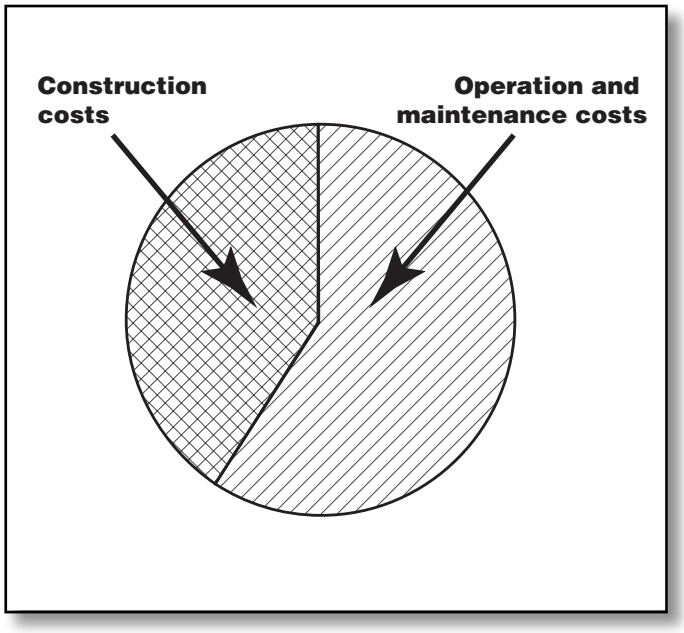

Figure 1—Over 30 years, the cost of operation and maintenance for buildings is more than the initial construction cost; how much more depends on the building type and location.

The largest expenditures over time for office buildings are the salaries and benefits for the employees who work there. This cost can be many times the cost of the building. For example, at the Missoula Technology and Development Center, salaries run around $16,400 a day. In less than 2 years after the new MTDC building was occupied in 2003, the amount paid to the employees who work there had exceeded the initial cost of construction of about $113 per square foot. Over 30 years, salaries and benefits will be about 18 times the initial cost of construction (figure 2). Because employee productivity is affected by the quality of the space where they work, employee productivity could be considered the single most important factor when evaluating the long-term cost effectiveness of any building design.

Life-cycle cost analysis (LCCA) is the tool that can tell you whether it makes economic sense to invest in a particular building component or system or whether one building design will be more cost effective over time than another. LCCA is particularly useful for comparing the costs of several options for equipment, systems, or buildings so you can make smart choices for a particular situation. For instance, an LCCA can help you determine whether it would be more cost effective to replace deteriorating window-mounted air conditioners in an office with new window-mounted air conditioners, a refrigerated central air conditioning system, or a ground-source cooling system. The answer may be different depending on climate, energy costs, and whether you plan to keep the building indefinitely or dispose of it in a few years. LCCA can account for all those variables and more.

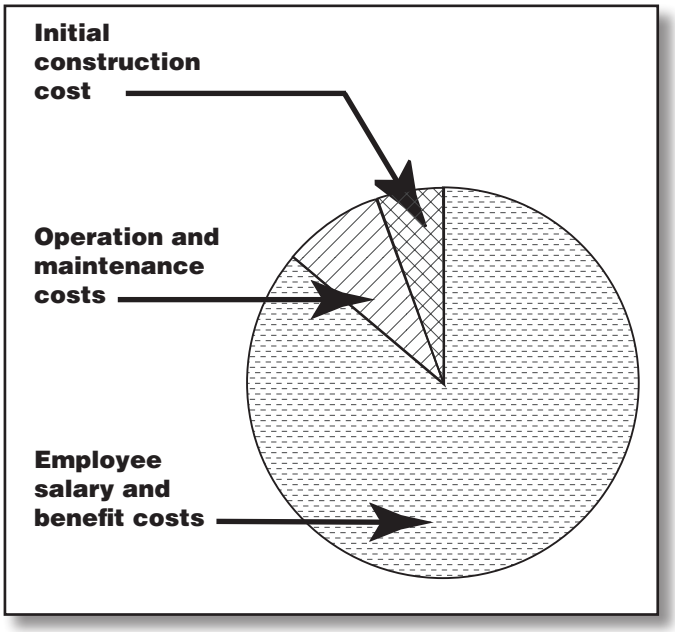

Figure 2—Over 30 years, the costs of employee salaries and benefits dwarf both the original construction cost and the operation and maintenance cost of the office building where they work.

Life-Cycle Cost Analysis Is Required for Forest Service Buildings

Not only is it smart to use LCCA rather than just considering initial cost when evaluating design, lease, and purchase options, it's also required.

- **Forest Service Handbook 7309.11, section 23.4**—Standards for Economic Analysis (*http://www.fs.fed.us/im/directives/fsh/7309.11/7309.11_20.doc*)
- **Executive Order No. 13327, Federal Real Property Asset Management** (*http://a257.g.akamaitech.net/7/257/2422/14 mar20010800/edocket.access.gpo.gov/2004/pdf/04-2773.pdf* or *http://www.gsa.gov/Portal/gsa/ep/contentView.do?contentType=GSA_BASIC&contentId=16911&noc=T*)
- **Executive Order No. 13423, Strengthening Federal Environmental, Energy, and Transportation Management** (*http://a257.g.akamaitech.net/7/257/2422/01jan20071800/edocket.access.gpo.gov/2007/pdf/07-374.pdf* or *http://www.gsa.gov/Portal/gsa/ep/contentView.do?P=MTL&contentId=22395&contentType=GSA_BASIC*)
- **The Energy Conservation Standards for New Federal Commercial and Multi-Family High-Rise Residential Buildings and New Federal Low-Rise Residential Buildings** (*http://edocket.access.gpo.gov/2007/E7-24615.htm*)

Basic Life-Cycle Cost Analysis Calculation

LCCA is a well-defined procedure for estimating the overall costs of project alternatives. It is commonly accepted throughout the business and engineering community. Basically, LCCA consists of adding all the initial and ongoing costs of the structure, product, or component over the time you expect to be using it, subtracting the value you can get out of it at the end of that time, and adjusting for inflation.

A lot of information must be assembled and manipulated to accomplish a life-cycle cost analysis, but the basic formula is fairly straightforward. ASTM International, originally known as the American Society for Testing and Materials, develops and publishes technical standards for materials, products, systems, and services. ASTM standard E917-02 "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems" (*http://webstore.ansi.org/RecordDetail.aspx?sku=ASTM+E917-05*) is the standard industry procedure for analyzing life-cycle costs.

More detailed information about applying LCCA to Federal projects is contained in the National Institute of Standards and Technology Handbook 135, Life-Cycle Costing Manual (*http://www.bfrl.nist.gov/oae/publications/handbooks/135.pdf*).

Two factors make it difficult to use the formula for large projects:

- A lot of information has to be assembled and manipulated.
- All costs must be adjusted for inflation.

The term "present value" in the formula describes costs that have been adjusted for inflation, or "discounted." The emphasis on present value is important when considering expensive structures or components that function for many decades, because inflation can influence affordability. It's usually not worth calculating present value when analyzing the life-cycle costs of small or short-lived structures, products, or components.

Office of Management and Budget Circular A-94 (*http://www.whitehouse.gov/omb/circulars/a094/a094.html*) provides the guidelines and discount rates that must be used when determining present value for life-cycle cost analysis on major Federal projects. Circular A-94 requires that life-cycle cost analysis be calculated in terms of "net present value." Net present value is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the discounted costs from the discounted benefits. Discounting benefits and costs transforms gains and losses occurring in different time periods to a common unit of measurement.

The LCCA formula works for all projects, large or small. It is much easier to calculate the life-cycle cost of a window air conditioner than of a large laboratory building. The next two sections explain how to use a modified formula to analyze simple items such as window air conditioners and how to use software to analyze complex items such as a laboratory or office building.

Basic Formula for Calculating Life-Cycle Cost

The formula for calculating life-cycle cost is:

$$LCC = I + Repl - Res + E + W + OM\&R + O$$

LCC: Total life-cycle cost in present value (PV) dollars of a given alternative
I: Initial cost
Repl: PV capital replacement costs
Res: PV residual value (resale value, salvage value) less disposal costs
L: Desired useful life in years of the building or system
E: Total energy cost (PV)
W: Total water costs (PV)
OM&R: Total operating, maintenance, and repair costs (PV)
O: Total other costs, if any—contract administration costs, financing costs, employee salaries and benefits, and so forth (PV)

Life-cycle cost comparisons for building components or equipment (figure 3) can be accomplished relatively easily if there are no significant financing costs or differences in procurement costs among the options.

The following information is needed for a simple life-cycle cost analysis:

- The initial cost of each system.
- The expected life of each system (usually years).
- The expected average yearly maintenance, operation, and repair costs of each system.
- Maintenance and repair costs that occur only every several years, averaged over the time between occurrences.
- Operation, including fuel, electricity, and water use costs as well as ongoing costs such as operator wages, regular cleaning or restocking, etc.
- Any salvage or other residual value you will get out of the system when you have finished using it in this application.

Assembling this information can be a challenge. If the information isn't available in the manufacturer's literature or easily available records, you may need to call the manufacturer or supplier or ask knowledgeable people what their experience has been. The reliability of the results depends directly on the quality of the input. If you have enough experience with the system, you may be able to get close enough using estimated operation and maintenance costs.

Figure 3—Life-cycle cost analysis works well for small decisions, such as finding the most cost-effective replacement for the air conditioning system at the assistant ranger's house at the Bessey Ranger Station (Nebraska National Forest in the Rocky Mountain Region).

Choose a time period for the analysis and figure the cost for each system over that time period. The easiest time period to use is the shorter of:

- The number of years the most durable system is expected to last
- The number of years you expect to use the structure

Simple Formula for Calculating Life-Cycle Cost

Once you assemble all the information and choose your time period, plug the information for each of the systems into this formula:

LCC = I + Repl - Res + L (OM&R)

I = Initial cost (the easy part)

Repl = Replacement cost for any system that isn't expected to last the full time period. The replacement cost may need to be proportioned. For example, if the selected time period is 20 years, but the system will only last 15 years, you will need to include a replacement cost that is one-third of the full replacement cost. This is because two-thirds of the expected life of the replacement system will occur after the end of the time period you've chosen. Don't proportion the cost if the time period you select is the life of the structure, because once the structure's gone, you get no extra years of service from the system.

Res = Any remaining value you can recover at the end of the time period. If you can't sell it or trade it, there's none.

L = The time period you have chosen for the analysis.

OM&R = The yearly average operating, maintenance, and repair costs (including fuel and utility costs).

In case your memory of high school algebra is a little fuzzy, remember to multiply L times OM&R first, then add and subtract the factors in the order the equation is written. The result for each system is its life-cycle cost (LCC). You can compare the life-cycle costs of the different systems to learn which system is most cost effective over the time period you have chosen.

An LCCA that evaluates large systems or whole buildings usually considers so much information that assembling and tracking all of it becomes a major undertaking. Adding to the complexity, LCCA normally is used to compare the cost of several alternative designs of buildings and building systems (figure 4). Fortunately, several public domain programs and many proprietary programs are available to help with LCCA.

Figure 4—Comparing the life-cycle cost of several alternative designs often leads to selection of more durable and energy-efficient designs, such as the design for the Shoal Creek District Office (National Forests in Alabama, Southern Region).

The guidelines and discount rates in OMB Circular A-94 must be used for determining present value for life-cycle cost analysis on Forest Service projects. This report only provides information on public domain software with free download that complies with A-94 requirements and includes A-94 discount rates. Software tools that meet these criteria include:

- eVALUator, developed by Energy Design Resources
- Building Life-cycle Cost (BLCC), developed by the National Institute of Standards and Technology (NIST)

Both of these software tools were evaluated by using data to build a 1,400 square-foot single family residence with both contractor standard construction and sustainable design options for a 25-year analysis period. The sustainable design version of this house was built in Missoula, MT, in 2003 (figure 5). Evaluation of the sustainable design option was based on actual costs of materials and actual consumption of water, electricity, and natural gas. Estimated costs of materials and consumption of water, electricity, and natural gas were used for the contractor standard construction option. Actual utility rates and financing costs were used for both options. Identical information was used for each software tool. Both software programs returned roughly equivalent information. They both showed life-cycle cost savings over 25 years of around $29,000, simple payback in about 10 years, and adjusted internal rate of return of around 11 percent for the sustainable design option. You can see the results in the "Example LCCA Reports" section at the end of this document.

Figure 5—Public domain software tools were used to conduct life-cycle cost analyses on this 1,400 square-foot single family home. The results are given in the "Example LCCA Reports" section.

Both computer programs require that the user have enough knowledge of building design and performance to recognize the factors that will be important to get an accurate result. This should not be a problem for experienced engineers and architects, but might present problems for others. As with the basic LCCA formula explained above, initial cost, expected useful life, average yearly operation, maintenance, and repair costs; expected major component life and replacement costs; and salvage or other residual value must be determined. As explained in the "Other Software Tools for Life-Cycle Cost Analysis" section, other software tools are available to help calculate these costs, particularly the energy costs of different components.

The basic features, advantages, and limiting factors of the eVALUator and Building Life-Cycle Cost (BLCC) programs are explained below.

Based on the comparison and use of both of these programs, eVALUator would be better for most Forest Service life-cycle cost analyses, especially those for less complex buildings. It's quick, it's easy, it's accurate, and it provides enough information to enable informed decisions. For projects where more detailed information on energy use or financing is needed, BLCC would be better.

eVALUator

The eVALUator is a Microsoft Windows-based program that was developed to calculate the life-cycle benefits of investments that improve building design. It analyzes the financial benefits of buildings that reduce energy cost, raise employee productivity, and enhance users' satisfaction. eVALUator software is available at *http://www.energydesignresources.com/Resources/SoftwareTools/eVALUator.aspx*. Before downloading the software, most Forest Service employees will need to get temporary administrative rights to install new software by going to *http://gadgets.ds.fs.fed.us/EUTools/ad_promote.asp* and following the instructions.

Advantages

- eVALUator allows lots of flexibility and an unlimited range of building life. It allows occupant productivity, loan rate and term, discount rate, and capitalization rate inputs.
- It's easy and quick to input the information needed for analysis.
- It allows using different inflation rate assumptions for general costs, electricity costs, natural gas costs, operation and maintenance costs, capital purchase, and lease income.
- It automatically performs an uncertainty analysis and expresses bottom-line numbers with an associated "uncertainty band."
- Reports are straightforward, easy to configure for side-by-side comparison of alternatives, and easy to read. A sample eVALUator comparative analysis is included in the "Example Life-Cycle Cost Analysis Reports" section at the end of this report.

Limiting Factors

- The reports are not very detailed.
- When you try to install this program, it tells you it's downloading to a certain folder on the "C" drive, but it actually hides the executable (.exe) file in C:\Documents and Settings\(your shortname)\Local Settings\Temp\, and names it "setup.exe."
- The program was created in 2000, so it tries to install old versions of some software that the program needs to run—Forest Service users will almost certainly have newer versions on their computers already, so they must be careful to keep the newer versions when queried during setup. If the newer versions are not retained, the older versions will overwrite them and foul up other applications. The eVALUator program will work just fine with the newer versions.
- No residential uses are among the drop-down menu for building types, but "Other" works just fine.
- Lots of drop-down menu locations are available for California. Although the only choice outside California is "national average," the program works fine for facilities in the rest of the country.

Building Life-Cycle Cost

The Building Life-Cycle Cost (BLCC) program was designed to analyze energy and water savings, but it can accommodate any life-cycle cost analysis. The latest version of BLCC—BLCC5—is programmed in Java with an XML file format. The user's guide is part of the BLCC5 Help system. BLCC 5.3-07 contains the following modules:

- Federal Energy Management Program (FEMP) Analysis, Energy Project—For energy and water conservation and renewable energy projects under the FEMP rules based on 10 Code of Federal Regulations 436.
- Federal Analysis, Financed Project—For Federal projects financed through Energy Savings Performance Contracts (ESPC) or Utility Energy Services Contracts (UESC) as authorized by Executive Order No. 13123 (June 1999).
- OMB Analysis—For projects subject to OMB Circular A-94 for Federal Government construction projects that are not related to energy and are not water resource projects.
- Three programs with special features specifically required by the U.S. Department of Defense.

BLCC software is available at *http://www1.eere.energy.gov/femp/information/download_blcc.html*. Before downloading the software, most Forest Service employees will need to get temporary administrative rights to install new software by going to *http://gadgets.ds.fs.fed.us/EUTools/ad_promote.asp* and following the instructions. BLCC 5.3-08 became available just before this report was printed. It contains updated energy price indexes and discount factors, but is otherwise the same as BLCC 5.3-07.

Advantages

- This program is very flexible. It allows you to consider as much or as little detail as you need for the level of analysis and for the building size and type.
- It appears to be the standard, at least for Federal Government work.
- It calculates life-cycle costs, net savings, savings-to-investment ratio, adjusted internal rate of return, and payback for any alternative relative to a base case.
- Reports provide good detail on payback time, energy consumption (in dollars, kilowatt hours, therms, and British thermal units), and emissions. A sample BLCC comparative analysis is included in the "Example LCCA Reports" section at the end of this report.
- Reports are straightforward, easy to read, and easy to set up.

Limiting Factors

- Life-cycle costs can't be computed for longer than 25 years.
- The financing information for the "Federal Analysis, Financed Project" option must be entered in a format that is not intuitive to people who aren't normally involved in financial calculations.
- Employee productivity is not a component of this software.

Other Software Tools for Life-Cycle Cost Analysis

Software tools are available that can support or supplement LCCA. Most of these programs concentrate on energy efficiency and will perform a limited LCCA for energy use. The data from these programs can be entered into eVALUator or BLCC to produce more accurate life-cycle cost comparisons.

Options for heating, ventilating, air conditioning, windows, insulation, lighting, shading, appliances, office equipment, water heating, building orientation, and roofing can be evaluated with software tools. Unfortunately, no single tool covers everything. An alphabetical list, brief summaries, and Web addresses of many of these software tools are available in the "Life-Cycle Cost Analysis Software" section at the end of this report.

The Northern Region has developed a spreadsheet for calculating life cycle costs. Forest Service and Bureau of Land Management employees can access the spreadsheet at *http://fsweb.mtdc.wo.fs.fed.us/toolbox/fmp/documents/lcca.xls*.

While a life-cycle cost analysis is a financial tool, a life-cycle assessment evaluates the environmental costs associated with a product, process, structure, or activity by identifying energy and materials used and wastes released to the environment. In this context, the term “life cycle” means the assessment considers everything that goes into or is produced as a result of the product or service. This starts with production of raw materials and includes manufacture, distribution, use, disposal, transportation, and the energy used by the product, process, structure, or activity. This is sometimes referred to as a "cradle-to-grave" (figure 6) assessment. The sum of the cradle-to-grave environmental costs is the life-cycle environmental cost of the product.

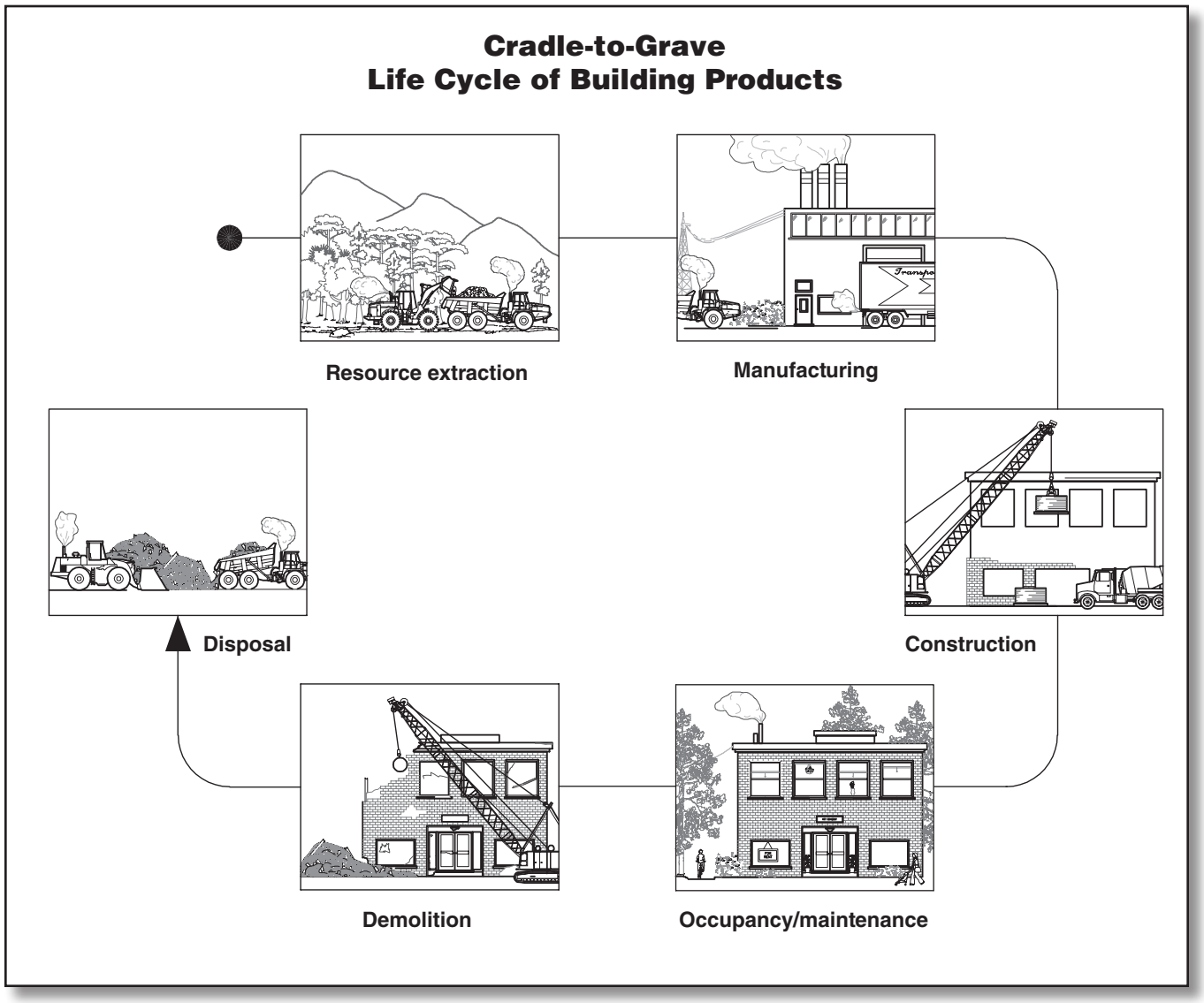

Figure 6—In a cradle-to-grave life cycle, building materials are used once and then discarded.

Some products can be partly or completely reused or remanufactured into new products after they have served their original purpose. In these cases, the cycle is often referred to as "cradle-to-cradle" (figure 7). An example of a cradle-to-cradle product is an aluminum beverage can. Aluminum production is extremely energy intensive, but aluminum is fully recyclable no matter how many times it has already been recycled. Manufacturing new cans from recycled cans cuts energy use by 95 percent, making aluminum cans a cradle-to-cradle product. Unfortunately, only about half of the aluminum cans produced in the United States are recycled, so there's still some "grave" in aluminum can production.

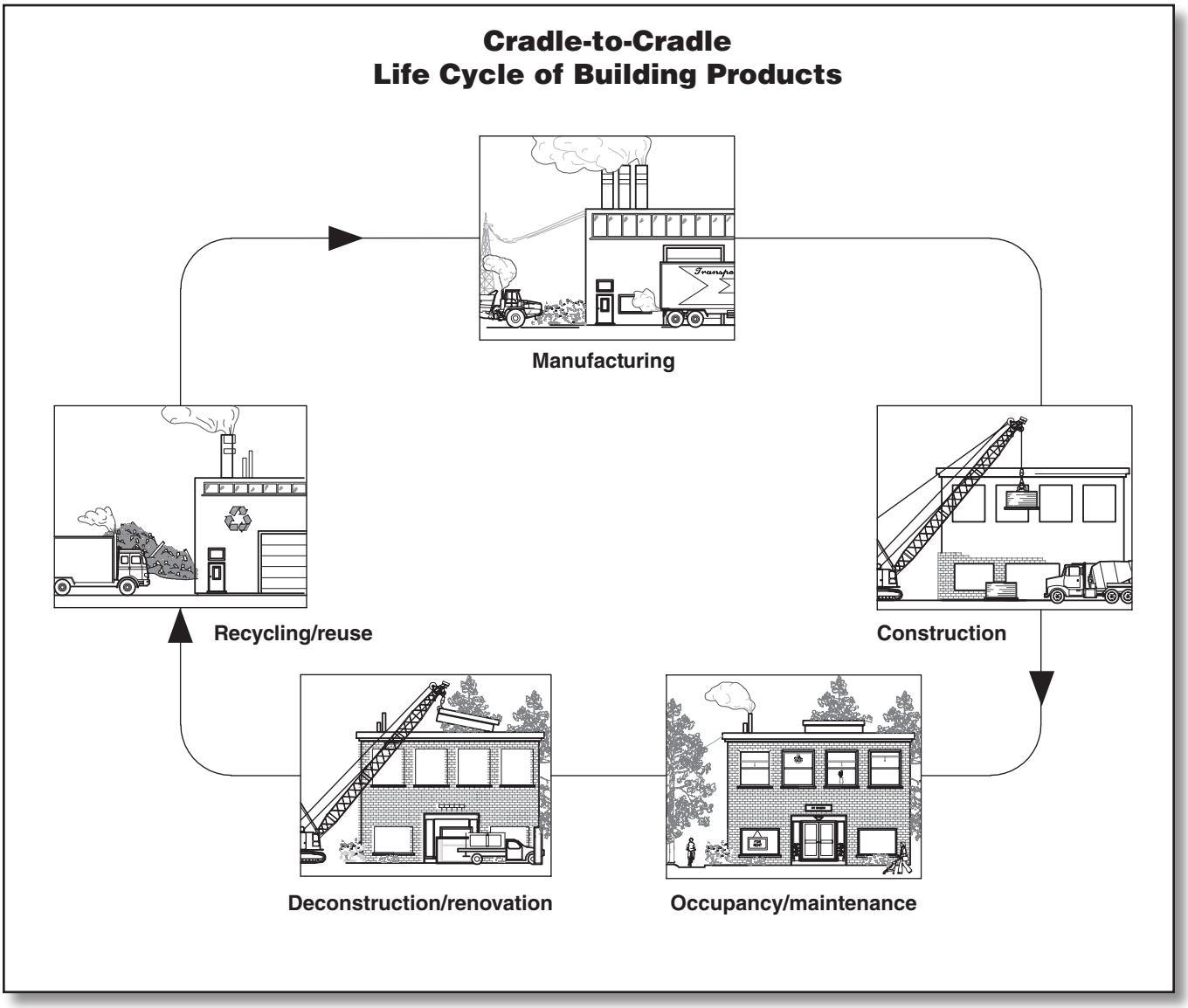

Figure 7—Building materials that are no longer needed for their original purpose are recycled or reused in a cradle-to-cradle life cycle.

To illustrate the life-cycle assessment process, consider a comparison of the environmental costs of beverage packaging made of glass, aluminum, and plastic. Cradle-to-cradle assessments for all three options must be performed. For glass bottles, this would include mining of silica and other minerals, proportional costs of recycled content, bottle production, bottling, transport, and disposal or recycling. For aluminum, the assessment would include mining bauxite, production of aluminum (including proportional costs of recycled content), production of cans, filling the cans, transport, and disposal or recycling. For plastic bottles, the assessment would include raw oil production, oil refining, proportional costs of recycled content, polymer production, bottle production, bottling, transport, and disposal or recycling. The analysis must include proportional life-cycle costs of products that go into the manufacture or use of each product, such as catalysts needed during the production of the plastic polymer. Raw materials mined or grown, land uses, noise generation, releases of pollutants to the air, water, or soil, and all other ecological costs are evaluated and compared.

Identifying all these environmental costs is difficult and time consuming. To ease the process, several analysis programs have been developed. An alphabetical list, brief summaries, and Web addresses of some of these software tools are available in the "Life-Cycle Assessment Software" section at the end of this report. Each program provides different advantages, levels of detail, weights for different sorts of environmentally detrimental factors, and ability to provide meaningful output for nonstandard materials and assemblies.

Although life-cycle assessment is not required for Forest Service structures, it can provide valuable information that can help decisionmakers choose more environmentally friendly materials and systems.

Summary

Life-cycle cost analysis is not as difficult as it might appear to be. By using the simplified formula explained in this report for small decisions and the eVALUator or BLCC and supplemental software for large decisions, Forest Service decisionmakers will have the financial information they need to make responsible maintenance, improvement, and construction choices. Because decisions based on life-cycle cost effectiveness almost always lead to decisions to purchase more durable and energy-efficient products and systems (figure 8), LCCA is good for the environment. In addition, life-cycle assessment software can be used to compare the environmental effects of different systems and products, leading to better informed choices about environmentally friendly materials and systems.

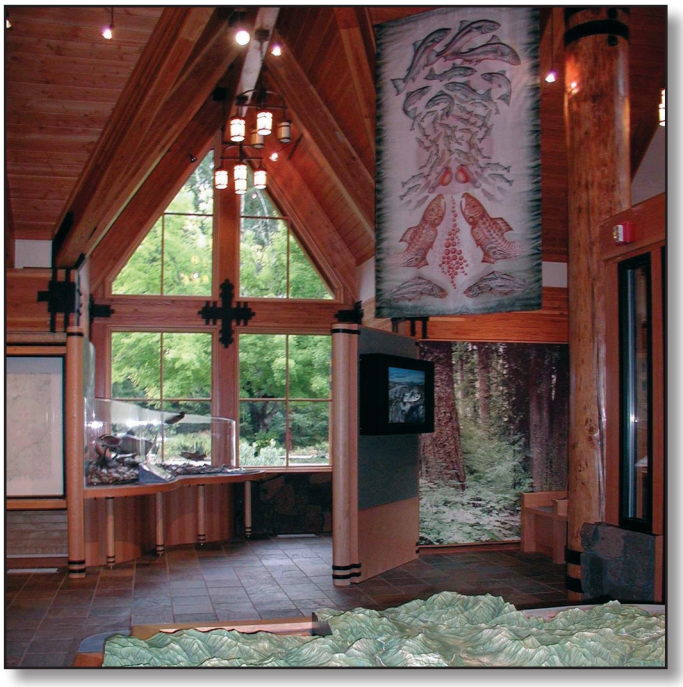

Figure 8—The durable wood walls and slate floors of the visitor information center and entry to the McKenzie River Ranger Station although initially expensive, will stand up to the demands of high visitor use far longer than less durable materials (Willamette National Forest, Pacific Northwest Region).

Free Software

Building for Environmental and Economic Sustainability (BEES) (*http://www.bfrl.nist.gov/oae/software/bees/*) is a tool that helps select cost-effective building products from more than 200 environmentally preferred items. BEES is based on consensus standards and measures the environmental performance of building products by using the life-cycle assessment approach specified in the International Organization for Standardization (ISO) 14040 series of standards (*http://www.iso.org/iso/home.htm*). BEES has been adapted for application to biobased products—see BEES for USDA (*http://www.bfrl.nist.gov/oae/software/bees/bees_USDA.html*). BEES has been supported in part by the U.S. Environmental Protection Agency's Environmentally Preferable Purchasing program (*http://www.epa.gov/epp/*).

The **Chilled Water System Analysis Tool** (*http://www1.eere.energy.gov/industry/bestpractices/software.html*) is used to determine the energy requirements of chilled water cooling systems and to evaluate opportunities for energy and cost savings by applying improvement measures. The program, developed by the U.S. Department of Energy (DOE), allows you to calculate the current energy consumption of an existing system, then select proposed equipment or operational changes for comparison.

The **Combined Heat and Power Application Tool** (*http://www1.eere.energy.gov/industry/bestpractices/software.html*) is used to evaluate the feasibility of combined heat and power. This tool, developed by the DOE, will estimate system costs and payback period. It also performs "what if" analyses for various utility costs. It includes performance data and preliminary cost information for many commercially available gas turbines and default values that can be adapted to meet specific application requirements.

The **Construction Waste Calculator** (*http://www.metrokc.gov/dnrp/swd/greenbuilding/construction-recycling/cost-effectiveness.asp*) from King County Solid Waste Division, WA, explains how to determine the cost effectiveness of recycling versus disposal by using the Recycling Economics Worksheet (*http://www.metrokc.gov/dnrp/swd/greenbuilding/documents/economics_worksheet.xls*). The worksheet contains separate calculation sheets for commercial-hauling and self-hauling options, as well as samples of completed worksheets.

The **Cool Roof Calculator** estimates cooling and heating savings for flat and low-slope roofs with surfaces that are not black. It includes DOE Web-based software programs for managers of small and medium-sized facilities that purchase electricity without a demand charge (*http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm*) and for large facilities that purchase electricity with a demand charge based on peak monthly load (*http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcPeak.htm).*

DOE-2 (*http://www.doe2.com/*) is a frequently updated FORTRAN program developed by James J. Hirsch & Associates in collaboration with Lawrence Berkeley National Laboratory. It calculates the hourly energy use and energy cost of a commercial or residential building based on user-supplied information about the building's climate, construction, operation, utility rate schedule, and heating, ventilating, and air-conditioning (HVAC) equipment. It can be used in its basic form or accessed through a friendlier interface such as eQUEST, EnergyPlus, Green Building Studio, or PowerDOE, all of which are described in this section.

Energy Cost Calculators (*http://www.fedcenter.gov/_kd/go.cfm?destination=ShowItem&Item_ID=8336*) from the Federal Energy Management Program allow users to enter their own utility rates, hours of use, and so forth, to estimate the energy cost savings from buying a more efficient product. Calculators are available for compact fluorescent lamps, commercial unitary air conditioners, air-cooled chillers, water-cooled chillers, commercial heat pumps, boilers, refrigerators, freezers, beverage vending machines, computers, monitors, faxes, printers, copiers, faucets/showerheads, toilets/urinals, central air conditioners, gas furnaces, electric/gas water heaters, clothes washers, and dishwashers.

Energy-10 (*http://www.nrel.gov/buildings/energy10.html*) from the National Renewable Energy Laboratory helps architects and building designers quickly identify the most cost-effective energy-saving measures for small commercial and residential buildings. It integrates daylighting, passive solar heating, and low-energy cooling strategies with energy-efficient shell design and mechanical equipment. It enables designers to make good decisions about energy efficiency early in the design process.

EnergyPlus (*http://www.eere.energy.gov/buildings/energyplus/*) is a DOE building energy simulation program for modeling a building's heating, cooling, lighting, ventilating, and other energy flows. It is based on the most popular features and capabilities of DOE-2, but it includes simulation capabilities such as time steps of less than an hour, modular systems, HVAC zone simulation, multizone air flow, thermal comfort, and photovoltaic systems.

eQUEST (*http://www.energydesignresources.com/resource/130*) was developed by Energy Design Resources to perform a detailed analysis of state-of-the-art building design technologies without requiring extensive experience in the "art" of building performance modeling. It combines a building creation wizard, an energy efficiency measure wizard, and a graphical results display module with a DOE-2 building energy-use simulation program. Results are displayed in tables and graphs. eQUEST appears to be one of the most popular energy-use simulation programs, probably because of its ability to display energy consumption over time using colorful, easy-to-read graphs and tables.

The **Financing Alternatives Comparison Tool** (*http://epa.gov/owm/cwfinance/cwsrf/fact.htm*) is a U.S. Environmental Protection Agency (EPA) financial analysis tool that helps identify the most cost-effective method to fund a wastewater or drinking water management project. This tool produces a comprehensive analysis that compares various financing options for these projects by incorporating financing, regulatory, and other important costs.

The **Life-Cycle Cost Analysis Model** (*http://www.green.ca.gov/LCCA/default.htm*) was developed by the State of California to determine the cost effectiveness of implementing energy conservation measures using the results of energy audits or energy feasibility studies. This Excel spreadsheet has information specific to California (details about energy costs, California energy tariffs, peak/part-peak/off-peak rates, etc.) already filled in, although the information can be modified. The model provides detailed analysis of energy cost savings and implementation costs.

Radiance (Windows version at *http://radsite.lbl.gov/deskrad/* and Unix version at *http://radsite.lbl.gov/radiance/*) is a tool for lighting design and rendering, developed by the DOE and the Swiss Federal Government through the Lawrence Berkeley National Laboratory. It quantitatively renders daylight in building models to provide graphic displays and luminance numbers that can be used to determine how much artificial lighting is needed in a room or how room configuration could be changed to eliminate the need for artificial light.

The **Target Finder** (*http://www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder*) is an EPA energy modeling tool that helps architects and building owners set aggressive, realistic energy targets and rate a commercial building's estimated energy use, based on the EPA's survey of existing buildings and climate by ZIP code. Site and source energy calculations are provided for both energy use intensity and total annual energy.

The **Unitary Air Conditioner Cost Estimator** (*http://www1.eere.energy.gov/femp/procurement/eep_unitary_ac_calc.html*) compares high-efficiency rooftop air conditioners to standard equipment in terms of life-cycle cost. This estimator, developed by the DOE, accounts for local climate and partial load as well as full load efficiencies. The Web-based, menu-driven format is easy to learn and use. It quickly estimates life-cycle cost, simple payback, return on investment, and the savings-to-investment ratio based on user-specified air conditioning requirements and building use patterns. Results are easily downloaded as graphic files for further analysis or for presentations.

Commercial Software

Ecotect (*http://squ1.com/*) is a whole-building simulator from Square One Research that "combines an interactive building design interface and 3D modeler with a wide range of environmental analysis tools for a detailed assessment of solar, thermal, lighting, shadows and shading design, energy and building regulations, acoustics, air flow, cost, and resource performance of buildings at any scale." It works with Square One's CAD engine, or you can import building information from AutoCAD.

Green Building Studio (*http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=11179531*) is one of the many interfaces to DOE-2. It also is compatible with other energy-analysis software. Green Building Studio has tools that help evaluate building designs for energy consumption and carbon footprints.

PowerDOE (*http://www.doe2.com/Download/Docs/D22PDSum.pdf*) is a commercial interface to DOE-2 (see the "Free Software" section) that uses graphics, building images, and models to both organize data input and display building energy use for heating, cooling, lighting, ventilating, and so forth.

The **Virtual Environment** (*http://www.iesve.com/content/default.asp?page=home_Our%20Software*) can act as a plugin to AutoCAD's Revit, calculating heating and cooling loads. Developed by Integrated Environmental Solutions, Ltd. This plugin can also be used to model several other systems from within Revit.

Life-Cycle Assessment Software

Free Software

Building for Environmental and Economic Sustainability (BEES) (*http://www.bfrl.nist.gov/oae/software/bees/*) is a tool that helps select cost-effective building products from more than 200 environmentally preferred items. BEES is based on consensus standards and measures the environmental performance of building products by using the life-cycle assessment approach specified in the International Organization for Standardization (ISO) 14040 series of standards (*http://www.iso.org/iso/home.htm*). BEES has been adapted for application to biobased products—see BEES for USDA (*http://www.bfrl.nist.gov/oae/software/bees/bees_USDA.html*). BEES has been supported in part by the U.S. Environmental Protection Agency's Environmentally Preferable Purchasing program (*http://www.epa.gov/epp/*).

Building Materials Reuse Calculator (*http://www.wastematch.org/calculator/calculator.htm*) from New York City's NY Wa$teMatch Materials Exchange estimates the environmental benefits of salvaging and reusing building materials, rather than buying and installing new ones. The calculator measures the environmental benefits of reusing building materials.

Pharos (*http://www.pharoslens.net/about/*) is a labeling system that is sponsored by the Healthy Building Network and its partners. The labeling system, still being developed, is intended to be a consumer-friendly display of the evaluation of materials across impact categories, including energy/water usage, air quality impacts, toxicity, occupational safety, social justice, and habitat impacts. The PharosWiki (*http://www.pharosproject.net/wiki/index.php?title=Main_Page*) is available, although the labeling system was not yet available when this report was prepared.

Commercial Software

Impact Estimator for Buildings (*http://www.athenasmi.ca/tools/impactEstimator/*) allows comparisons of the environmental implications of conceptual designs. It covers more than 90 structural and envelope materials, simulates more than 1,000 different assembly combinations, and claims to be capable of modeling 95 percent of the building stock in North America. The software was developed by the nonprofit Athena Institute, a Canadian research and development organization that focuses on sustainability and life-cycle assessments of buildings.

eVALUator Comparative Analysis - Owner/Occupant Scenario

Analysis prepared for:	Occupant
	Missoula, MT
Base Case:	Standard
Alternative:	Actual

Initial Pro-Forma

Loan term	15 yr.
Loan interest rate	4.8%
Salary costs	$ / yr.
Productivity improvement	.0%

	Baseline	Alternative	Change
Project Cost	$200,000	$210,000	$10,000
% Financed	45.0%	45.0%	
Up-front Equity	$110,000	$115,498	$5,498
Annual Debt Service	$8,554	$8,982	$428
Non-Energy Expenses	$2,503	$1,499	-$1,004
Energy Expenses	$2,036	$1,039	-$997
Productivity Impacts	$0	$0	$0

Cash flow improvement	$1,573
Simple payback	10 yr.

Life Cycle Analysis (Net Present Value)

Discount Rate	5%
Analysis Period	25

	Baseline	Alternative	Change
Non-Energy Expenses	$49,203	$29,467	-$19,736
Energy Expenses	$40,772	$20,802	-$19,969
Productivity Impacts	$0	$0	$0
Up-front Equity	$110,000	$115,498	$5,498
Debt Service	$88,787	$93,225	$4,438
Replacement Costs	$8,431	$8,431	$0
Total Life Cycle Costs	$297,193	$267,423	-$29,770

Savings-to-Investment Ratio	4
Adj. internal rate of Return	11.0%

NIST BLCC 5.3-07: Comparative Analysis

Consistent with Federal life-cycle cost methodology and procedures, 10 CFR, part 436, subpart A

Base Case: standard Alternative: actual

General Information

File Name:	C:\Program Files\BLCC5\projects\occupant.xml
Date of Study:	Wed Nov 14 14:57:54 MST 2007
Project Name:	Occupant
Project Location:	Montana
Analysis Type:	FEMP Analysis, Energy Project
Analyst:	Occupant
Base Date:	November 1, 2007
Service Date:	November 1, 2008
Study Period:	25 years 0 months (November 1, 2007, through October 31, 2032)
Discount Rate:	5%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$200,000	$210,000	-$10,000
Future Costs:			
Energy Consumption Costs	$31,183	$15,625	$15,558
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$15,049	$8,332	$6,717
Recurring and Non-Recurring OM&R Costs	$41,108	$24,665	$16,443
Capital Replacements	$6,839	$6,839	$0
Residual Value at End of Study Period	-$3,207	-$3,207	$0
Subtotal (for Future Cost Items)	$90,972	$52,254	$38,718
Total PV Life-Cycle Cost	$290,972	$262,254	$28,718

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$38,718
- Increased Total Investment	$10,000
Net Savings	$28,718

Savings-to-Investment Ratio (SIR) **SIR** = 3.87

Adjusted Internal Rate of Return **AIRR** = 10.80%

Payback Period - Estimated Years to Payback (from beginning of Service Period)

Simple Payback occurs in year 8

Discounted Payback occurs in year 10

Energy Savings Summary

Energy Savings Summary (in stated units)

Energy Type	----Average Base Case	Annual Consumption---- Alternative	Savings	Life-Cycle Savings
Electricity	11,000.0 kWh	5,544.0 kWh	5,456.0 kWh	130,928.4 kWh
Natural Gas	700.0 Therm	348.0 Therm	352.0 Therm	8,447.0 Therm

Energy Savings Summary (in MBtu)

Energy Type	----Average Base Case	Annual Consumption---- Alternative	Savings	Life-Cycle Savings
Electricity	37.5 MBtu	18.9 MBtu	18.6 MBtu	446.7 MBtu
Natural Gas	70.0 MBtu	34.8 MBtu	35.2 MBtu	844.7 MBtu

Emissions Reduction Summary

Energy Type	----Average Base Case	Annual Emissions---- Alternative	Reduction	Life-Cycle Reduction
Electricity				
CO2	11,495.31 kg	5,793.63 kg	5,701.67 kg	136,823.86 kg
SO2	4.45 kg	2.24 kg	2.21 kg	52.99 kg
NOx	22.38 kg	11.28 kg	11.10 kg	266.34 kg
Natural Gas				
CO2	3,697.58 kg	1,838.23 kg	1,859.35 kg	44,619.22 kg
SO2	29.84 kg	14.84 kg	15.01 kg	360.09 kg
NOx	2.88 kg	1.43 kg	1.45 kg	34.76 kg
Total:				
CO2	15,192.89 kg	7,631.86 kg	7,561.03 kg	181,443.07 kg
SO2	34.29 kg	17.08 kg	17.21 kg	413.08 kg
NOx	25.26 kg	12.71 kg	12.55 kg	301.10 kg

Notes

About the Author

Kathleen Snodgrass came to MTDC as a project leader in 2001. She graduated from Washington State University in 1974 with a bachelor of science degree in architectural studies, then spent about 10 years in highway design and construction with the Idaho Division of Highways. She began her career with the Forest Service in 1984. Snodgrass worked in facilities, landscape architecture, land line, and general engineering on the Nez Perce National Forest for 10 years and was the forest's facilities architect for about 7 years before coming to MTDC.

Library Card

Snodgrass, Kathleen. 2008. Life-cycle cost analysis for buildings is easier than you thought. Tech. Rep. 0873–2839–MTDC. Missoula, MT: U.S. Department of Agriculture Forest Service, Missoula Technology and Development Center. 18 p.

Life-cycle cost analysis is a structured method of determining the entire cost of a structure, product, or component over its expected useful life by adding the cost of operating, maintaining, and using it to the purchase price. By using the simplified formula explained in this report for small decisions and the free software identified in this report for large decisions, Forest Service decisionmakers will have the financial information they need to make responsible decisions about replacing or constructing facilities. This report also includes a brief discussion of life-cycle assessments, which assess all of a product or service's environmental costs throughout its lifetime.

Keywords: A-94, ASTM, BLCC, buildings, climate, cradle, design, energy, environment, equipment, eVALUator, facilities, financial, LCCA, life-cycle assessments, maintenance, operating, performance, repair, replacement, software, sustainable, systems, value, water

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