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An American National Standard

Standard Guide for Evaluating Economic Performance of Alternative Designs, Systems, and Materials in Compliance with Performance Standard Guides for Single-Family Attached and Detached Dwellings[1]

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INTRODUCTION

This guide on economics is part of a set which together presents a complete performance guide for specifying and evaluating single-family attached and detached dwellings. The complete set in the series, when finished, is to include the following attributes:

A Structural Safety and Serviceability
B Fire Safety
C Accident Safety
D Health and Hygiene
E Indoor Air Quality
F Light
G Acoustics
H Durability
I Accessibility
J Security
K Economics
L Functionality
M Aesthetics
N Adaptability
O Maintainability
P Sustainability

The series provides a framework for specifying and evaluating qualities of building products and systems to meet user needs without limiting ways and means. The format for this series of standard guides includes performance statements that consist of four components—Objectives, Criteria, Evaluation, and Commentary (O-C-E-C)—which together provide a systematic performance-based approach for the intended purpose.

Each standard guide in the set presents a collection of information and a series of options available to the specifier. The standard guides include examples of performance statements that may be used for the specification and evaluation of residential designs, materials, products, components, subsystems, and systems.

1. Scope

1.1 *What This Guide Does*—This guide helps designers, builders, home owners, and other stakeholders to identify and evaluate benefits and costs in order to make efficient choices between two or more traditional alternatives and between traditional alternatives and new-technology products, systems, materials, and designs. It directs the users to ASTM classifications, practices, adjuncts, and computer programs that implement the appropriate economic method to evaluate these benefits and costs in making technology choices. The focus, however, is on a nine-step process for using two ASTM practices—life-cycle costing (LCC), E917, and the analytical

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hierarchy process (AHP), E1765—to measure and evaluate the economic and overall performance of investments in single-family attached and detached dwellings. This guide contains three appendixes. The first two are designed to help users identify and evaluate benefits and costs. Appendix X1 contains a classification of benefits and a methodology for estimating these benefits. Appendix X2 contains a classification of costs and a methodology for estimating these costs. Appendix X3 illustrates how to evaluate the economic performance of three alternative carpet materials, two traditional products and a new-technology product, when considering the guide for durability.

1.2 *Purpose of This Guide*—The purpose of this guide is to help users make cost-effective choices between traditional alternatives and new technologies permitted under performance standards. This guide (*1*) explains how the lack of economic information discourages the introduction of new technologies; (*2*) helps decision makers to identify and classify the key types of benefits and costs associated with both new technologies and traditional alternatives; (*3*) shows how to select alternatives that meet the performance standards, but cost less than traditional alternatives; and (*4*) shows how to incorporate nonfinancial information into the decision-making process, enabling performance to be defined and using costs and other criteria.

1.3 *Relationship of This Guide to Other Performance Standards Guides*—In this guide, economic analysis is used to evaluate and compare the economic performance of traditional alternatives and new technologies permitted under performance standards for single-family attached and detached dwellings. Use this economic analysis guide in evaluating alternatives permitted under any of the other 15 performance attributes, either singly or in combination. The objective of economic analysis in this guide is to identify cost-effective choices among traditional alternatives and new technologies permitted under performance standards. The other 15 performance attributes define the scope of the economic analysis. That is, cost-effectiveness derives from better economic value while providing comparable or better technical performance for each attribute's O-C-E-C performance statements. Consequently, to evaluate the economic performance of alternative residential designs, materials, products, components, subsystems, or systems permitted under performance standards, the user of this guide must first select one or more attributes, use the O-C-E-C framework to develop and present the corresponding performance statements, and identify the alternatives to be evaluated. Appendix X3, for example, evaluates carpeting with respect to the durability attribute and the economics attribute.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions

E833 Terminology of Building Economics

E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems

E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems

E1557 Classification for Building Elements and Related Sitework—UNIFORMAT II

E1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems

E2151 Terminology of Guides for Specifying and Evaluating Performance of Single Family Attached and Detached Dwellings

2.2 *ASTM Adjuncts:*

Discount Factor Tables, Adjunct to Practice E917

Computer Program and User's Guide to Building Maintenance, Repair, and Replacement Database for Life-Cycle Cost Analysis, Adjunct to Practices E917, E964, E1057, E1074, and E1121

Computer Program and User's Guide to AHP/Expert Choice for ASTM Building Evaluation, Adjunct to Classifications E1557, E1660 through E1671, E1693, E1694, E1700, and E1701, and Practices E917, E964, E1057, E1074, and E1765

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminologies E631, E833, and E2151.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *building economics, n*—the application of economic analysis to the design, financing, engineering, construction, management, operation, maintenance, repair, ownership, or disposition of buildings.

3.2.2 *commentary, n*—an informative narrative explaining aspects of the performance statement.

3.2.2.1 *Discussion*—The commentary explains how the objective relates to user needs in fields such as physiology, psychology, and tradition; how the criteria are established, including guides for setting different levels of performance to meet various user needs; and the reliability of the evaluation method. The commentary also includes example solutions that are deemed to comply with the performance statement.

3.2.3 *criteria, n*—quantitative statements defining the level or range of performance necessary to meet an objective or, where such a level or range cannot be established, the units of measurement of the performance.

3.2.4 *evaluation, n*—the method of assessing conformance of the element being addressed to the criteria.

3.2.4.1 *Discussion*—The evaluation states the standards, inspection methods, analysis, review procedures, historical documentation, test methods, in-use performance, engineering analyses, models, or other means to be used in assessing whether or not a criterion has been satisfied.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.5 *specifier, n*—the individual or organization using the standard guides to specify and accept designs, materials, products, components, subsystems, or buildings to be provided by providers.

3.2.6 *user need, n*—a statement of the activities and behavior to be carried out in relation to the dwelling by its residents, or other users, defined in terms of motor, kinetic, physiological, psychological, emotional, and other parameters of human behavior.

4. Significance and Use

4.1 *Why This Guide Is Needed*—The lack of information on economic consequences discourages the introduction of new technologies permitted under performance standards. The economic information needs are further complicated because decisions to adopt or accept a new technology are made by different types of stakeholders (for example, building materials manufacturers, home builders, and home owners). Thus, the type of economic information treated in this guide and the associated standard classifications, practices, adjuncts, and computer programs covers the information needs of the entire group of key stakeholders.

4.2 *Use of This Guide by Specificers and Providers*—To make efficient choices, decision makers require factual information on both how a particular alternative addresses the relevant performance statements and how much it costs. The O-C-E-C framework enables the specifier to develop the performance statements that satisfy one or more user needs and incorporate them into a request for proposals. Providers respond to the request for proposals by offering designs, materials, products, components, subsystems, or systems for acceptance. Because cost is one aspect of each provider's response, the specifier has an opportunity to request information from the provider that may be used in evaluating economic performance. This guide is intended as a resource from which the specifier compiles lists of information to be collected as part of each provider's response to the request for proposals. It is also intended for use by providers in preparing their response to the specifier. The generic types of information that the specifier may request from the provider in their response to the request for proposals are described in Appendix X1 for benefits and Appendix X2 for costs. A detailed example based on the durability attribute is given in Appendix X3.

4.3 *Use of Economic Tools for Evaluating New Technologies*—Having a package of economic tools (methods and software) that helps decision makers identify and evaluate benefits and costs when choosing between traditional alternatives and new-technology products, systems, materials, and designs will accelerate the introduction and acceptance of new technologies which are cost effective.

4.4 *Use of ASTM Standards on Building Economics*—Standard practices for using life-cycle costing (LCC), E917, and the analytical hierarchy process (AHP), E1765, to measure the economic and overall performance of investments in buildings and building systems have been published by ASTM. Two computer programs[3,4] that produce economic measures consistent with these practices are available. The Building Maintenance, Repair, and Replacement Database Program and the Discount Factor Tables have been published (Adjuncts to E917) by ASTM to facilitate computing measures of performance for the LCC practice. The economic tools described in this guide apply to the evaluation of all the building elements as described in the series of performance standard guides as well as in the UNIFORMAT II elemental Classification E1557.

4.5 *Features and Limitations of Economic Tools*—For a description of how to calculate the economic measures, how to interpret them, and their limitations, see Practice E917 for the LCC method and Practice E1765 for the AHP method.

5. Performance Statements

5.1 *Objective*—Select the alternative (design, material, product, component, subsystem, or system) that results in the best economic value while satisfying the technical performance criteria of one or more performance attributes.

5.2 *Criteria:*

5.2.1 *Life-Cycle Costing*—Select the alternative that minimizes life-cycle cost while satisfying the technical performance criteria of one or more performance attributes.

5.2.2 *Analytical Hierarchy Process*—Select the alternative that maximizes the final overall desirability score while satisfying the technical performance criteria of one or more performance attributes.

5.3 *Evaluation:*

5.3.1 *Life-Cycle Costing*—Use Practice E917.

5.3.2 *Analytical Hierarchy Process*—Use Practice E1765.

5.4 *Commentary*—Use the nine-step process outlined in 6.1 – 6.9 to evaluate the economic performance of each alternative and select the best economic choice.

6. How to Use This Guide

6.1 *Select the Performance Attribute(s)*—Select one or more of the other fifteen ASTM performance attributes. Use the O-C-E-C framework to develop and present the corresponding performance statements for the performance attribute(s) of interest. Use information received from providers in response to the specifier's request for proposals, or by other means, as a source of data to support the economic analysis.

6.2 *Select the Building Alternatives to be Evaluated*—Select at least two building alternatives for evaluation. Designate one alternative as the base case. It is generally easiest to use a traditional alternative (that is, design, system, or material) as the base case. Select one or more new-technology or conventional alternatives to be evaluated *vis-à-vis* the base case. Select only alternatives which are acceptable substitutes in performance for the base-case alternative.

[3] Petersen, S.R., *BLCC-The NIST "Building Life-Cycle Cost" Program, Version 4.3, User's Guide and Reference Manual*, NISTIR 5185-3, Gaithersburg, MD: National Institute of Standards and Technology, 1995.

[4] Chapman, R.E., Marshall, H.E., and Forman, E.H., *User's Guide to AHP/Expert Choice for ASTM Building Evaluation*, MNL 29, West Conshohocken, PA: American Society for Testing and Materials, 1998.

6.3 *Select the Economic Method:*

6.3.1 *Life-Cycle Costing* (Practice E917)

6.3.1.1 The life-cycle cost (LCC) method provides a framework for comparing life-cycle costs of alternative building designs, systems, or materials that satisfy the same performance statements.

6.3.1.2 The LCC method measures, in present-value or annual-value terms, the sum of all relevant costs associated with owning, operating, and disposing of a building, building system, or associated building materials, or a combination thereof, over a specified time period, referred to as the study period.

6.3.1.3 The basic premise of the LCC method is that, to an investor or decision maker, all costs arising from an investment decision are potentially important to that decision, including future as well as present costs. Applied to buildings or building systems, the LCC encompasses all relevant costs over a designated study period, including the costs of designing, purchasing/leasing, constructing/installing, operating, maintaining, repairing, replacing, and disposing of a particular building design, system, or material.

6.3.1.4 A comprehensive example of the LCC method applied to a building economics problem is provided in Appendix X3. The example illustrates the LCC method by focusing on issues that relate to the durability attribute. The economic performance of three alternative carpet materials are evaluated—two traditional products and a new-technology product.

6.3.2 *Analytical Hierarchy Process* (Practice E1765)

6.3.2.1 The analytical hierarchy process (AHP) is appropriate when multiple criteria, not all of which can be framed as costs, are to be considered in making an investment decision. The AHP is a procedure for breaking down a complex problem into its component parts (that is, evaluation criteria and alternatives), arranging these parts into a hierarchical form, deriving numerical values (that is, scores) based on subjective judgments and facts about the relative importance of criteria and the relative preference for alternatives, and synthesizing the information to arrive at a decision.

6.3.2.2 In addition to monetary benefits and costs, the AHP allows for the consideration of characteristics which decision makers regard as important, but which are not readily expressed in monetary terms.

6.3.3 Determine which economic method, LCC or AHP, is to be used. The LCC is appropriate for all fifteen attributes. The AHP is appropriate for all fifteen attributes as well. However, when choosing among building alternatives, all AHP applications are constrained to include LCC as a criteria element. A key distinction between AHP and LCC is that AHP applications evaluate the importance of exceeding the performance statements for one or more criteria elements for the selected performance attribute(s). This distinction is particularly useful in cases where several alternatives have values of life-cycle cost close to the minimum.

NOTE 1—Because some performance attributes may be of greater importance in meeting user needs, a decision maker may use the AHP to select a subset of the performance attributes from which to develop performance statements.

NOTE 2—If, for a given performance attribute, an element within the hierarchy of building elements contains more than one objective, then the AHP provides a means for selecting which objective is of greater importance in meeting user needs. If, for a given performance attribute, an objective contains more than one criteria element, then the AHP provides a means for selecting which criteria element is of greater importance in meeting user needs.

NOTE 3—If an alternative for a given performance attribute has no measurable future costs, then its life-cycle cost over the study period may be approximated by its first cost. If a competing alternative has measurable future costs over the study period, then include these costs when calculating its life-cycle costs. In calculating and evaluating economic performance (see 6.8 and 6.9), all alternatives must satisfy the same set of performance statements over the same study period.

6.4 *Identify Stakeholder Group(s)*—Because individual stakeholders are affected in different ways by choices between traditional alternatives and new technologies permitted under performance standards, it is useful to first identify classes of individual stakeholders and then classify them into stakeholder groups. By developing a classification hierarchy of stakeholders, we are better able to understand and identify both potential opportunities (that is, real or perceived benefits and cost savings accruing to that stakeholder) and potential barriers (that is, real or perceived additional costs and benefit reductions borne by that stakeholder) to choices between traditional alternatives and new technologies permitted under performance standards. Refer to Tables 1 and 2 to identify the appropriate type(s) of individual stakeholder(s) and corresponding stakeholder group(s) for the application under analysis. Table 1 is a hierarchy of stakeholders; it lists stakeholder groups with their corresponding types of individual stakeholders. Table 2 is arranged as a checklist; it assigns each individual stakeholder type to its corresponding stakeholder group(s). Note that an individual stakeholder may be associated with more than one stakeholder group. For example, government agencies are associated with three stakeholder groups. If information on all types of stakeholders is desired, then proceed directly to 6.5. Otherwise, review the types of individual stakeholders to determine which one (or ones) is (are) appropriate. Either Table 1 or Table 2 may be used to select which type(s) of individual stakeholder(s) is (are) appropriate. Use whichever table is most convenient for the application under analysis to select the individual stakeholder(s). Table 1 is presented as a hierarchy to show how the stakeholder groups are formed. Table 2 lists the types of individual stakeholders in alphabetical order to facilitate cross-referencing of individual stakeholders and stakeholder groups. Based on the selected individual stakeholder(s), use Table 2 to produce a list of the corresponding stakeholder group(s).

6.5 *Identify Key Types of Benefits and Costs*—Refer to Tables 3-5 to identify the key types of benefits and costs. Follow the procedure described in 6.5.1 – 6.5.3 to compile a composite list of benefits and a composite list of costs. Each composite list results in those benefits or costs which are relevant for the selected performance attribute(s) and the identified stakeholder group(s). Any benefits or costs which do not appear on a composite list may be excluded from the economic evaluation.

6.5.1 *Match Benefits and Costs to the Selected Performance Attribute(s)*—Table 3 is arranged by performance attribute; it lists key types of benefits by performance attribute. Because

TABLE 1 Hierarchy of Stakeholders: Stakeholder Groups and Individual Stakeholder

Product Development and Testing:
Product innovators
Product designers
Building materials manufacturers
Building products manufacturers
Research organizations
Government agencies
Testing laboratories/services
Codes, Standards, and Support Services:
Code organizations
Code officials
Standards organizations
Research organizations
Government agencies
Evaluation services/product certification
Building permitting and inspection
Manufacturing Interest Group:
Building materials manufacturers
Building products manufacturers
Commodity suppliers (raw materials)
Trade associations
Construction and Associated Support Services:
Home builders
Specialty trade contractors
Wholesale/retail trade/supply
Construction specifiers
Procurement officials
Owners/Managers/Developers/Users:
Developers
Home owners/renters
Housing managers
Government agencies
Professional Services:
Designers/architects
Engineering consultants
Lawyers
Municipal planners
Facility planners
Real estate companies/brokers
Financial Services:
Financial institutions
Insurance companies
Warranty companies
Other:
Utilities
Environmental interest groups
Housing disposition
Third parties

each type of cost applies to all performance attributes, a separate table listing key types of costs by performance attribute is not necessary. For the selected attribute(s), extract from Table 3 a list of the key types of benefits. Note that Table 3 combines information—key types of benefits—on all stakeholder groups. If information on all stakeholders is desired, it is sufficient to use only Table 3 to identify the key types of benefits. Otherwise, it is necessary to use all three tables to identify the key types of benefits and costs.

6.5.2 *Match Benefits and Costs to the Identified Stakeholder Group(s)*—Tables 4 and 5 are arranged by stakeholder group. Table 4 lists key types of benefits by stakeholder group; Table 5 lists key types of costs by stakeholder group. If information on only a single stakeholder group is desired, then select the appropriate column in each table, go down the column, and extract from it a list of the relevant types of benefits (Table 4) and the relevant types of costs (Table 5) for the stakeholder group. If information on more than one stakeholder group is desired, then follow the procedure just described for each stakeholder group. Combine each stakeholder group list into two lists: one for key types of benefits and one for key types of costs.

6.5.3 *Compile Composite List of Benefits and Costs*—Compare the list of the key types of benefits extracted from Table 3 with the list of benefits extracted from Table 4. Keep only those benefits which appear on both lists. Finally, produce two composite lists: one list for key types of benefits and one list for key types of costs.

6.6 *Identify and Collect Economic Data*—Refer to Appendix X1 for benefits and Appendix X2 for costs to identify the economic data associated with the key types of benefits and costs for the selected attribute(s) and the identified stakeholder group(s). Produce two lists of economic data: one list for the key types of benefits identified and one list for the key types of costs identified. Finally, collect the data and compile them in a form suitable for analysis.

6.7 *Review the Standard Practice Associated with the Economic Method*—Examine Practices E917 and E1765 to see which corresponds to the chosen economic method. In the selected practice, read the sections on significance and use, applications, and limitations. If the practice still seems appropriate, follow its procedures. If not, repeat the process until an acceptable practice has been found or it has been determined that neither of the practices is suitable for the decision at hand.

6.8 *Calculate the Economic Performance Values for Each Alternative*—For assistance in calculating the measure of economic performance provided by the selected method, use the three adjuncts. The adjunct on Discount Factor Tables supports manual calculations for the LCC method. The ASTM Database Program also supports the LCC method; it helps you estimate maintenance, repair, and replacement data. In addition, the Building Life-Cycle Cost Computer Program and User's Guide[5] supports the LCC method. For AHP calculations, use the AHP/Expert Choice for ASTM Building Evaluation software product[6] or similar commercially available software. Set up the decision problem so that the alternatives may be ranked in descending order according to their final overall desirability score.

6.9 *Evaluate the Economic Performance of Each Alternative*—If the LCC method is being used, select the alternative which satisfies the performance statements of the attribute(s) in question and minimizes life-cycle cost over the proposed study period. If the AHP method is being used, select the alternative which maximizes the "final overall desirability" score while satisfying the performance statements of the selected attribute(s).

[5] Petersen, S.R., 1995.
[6] Chapman, R.E., Marshall, H.E., and Forman, E.H., 1998.

TABLE 2 Assignment of Individual Stakeholders to Stakeholder Groups

Individual Stakeholders	Stakeholder Groups							
	Product Development and Testing	Codes, Standards, and Support Services	Manufacturing Interest Group	Construction and Associated Support Services	Owners/ Managers/ Developers/ Users	Professional Services	Financial Services	Other
Building materials manufacturers	✓		✓					
Building permitting and inspection		✓						
Building products manufacturers	✓		✓					
Code officials		✓						
Code organizations		✓						
Commodity suppliers (raw materials)			✓					
Construction specifiers				✓				
Designers/architects						✓		
Developers					✓			
Engineering consultants						✓		
Environmental interest groups								✓
Evaluation services/product certification		✓						
Facility planners						✓		
Financial institutions							✓	
Government agencies	✓	✓			✓			
Home builders				✓				
Home owners/renters					✓			
Housing disposition								✓
Housing managers					✓			
Insurance companies							✓	
Lawyers						✓		
Municipal planners						✓		
Procurement officials				✓				
Product designers	✓							
Product innovators	✓							
Real estate companies/ brokers						✓		
Research organizations	✓	✓						
Specialty trade contractors				✓				
Standards organizations		✓						
Testing laboratories/services	✓							
Third parties								✓
Trade associations			✓					
Utilities								✓
Warranty companies							✓	
Wholesale/retail trade/supply				✓				

TABLE 3 Types of Benefits and Cost Savings Classified by Performance Attribute

Type of Benefit or Cost Saving	Performance Attribute														
	Structural Safety and Serviceability	Fire Safety	Accident Safety	Health and Hygiene	Indoor Air Quality	Light	Acoustics	Durability	Accessibility	Security	Functionality	Aesthetics	Adaptability	Maintainability	Sustainability
Exceeds minimum acceptable peformance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Improvements in health, safety, and security	✓	✓	✓	✓	✓		✓	✓		✓					
Increased occupant comfort					✓	✓	✓	✓							
Increased sales for building materials/ products manufacturers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Increased sales for systems design/integration/ optimization services	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lower conversion costs											✓		✓		
Lower energy costs					✓	✓	✓	✓			✓			✓	
Lower first costs	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Lower operations and maintenance costs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Promotes innovation in the construction industry	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reductions in warranty costs								✓			✓			✓	
Reductions in waste and pollution								✓			✓			✓	✓

TABLE 4 Types of Benefits and Cost Savings Classified by Stakeholder Group

Type of Benefit or Cost Saving	Stakeholder Group							
	Product Development and Testing	Codes, Standards, and Support Services	Manufacturing Interest Group	Construction and Associated Support Services	Owners/ Managers/ Developers/ Users	Professional Services	Financial Services	Other
Exceeds minimum acceptable performance				✓	✓	✓	✓	✓
Improvements in health, safety, and security				✓	✓	✓	✓	✓
Increased occupant comfort					✓			✓
Increased sales for building materials/products manufacturers	✓	✓	✓	✓	✓	✓		✓
Increased sales for systems design/integration/optimization services	✓		✓		✓	✓		
Lower conversion costs				✓	✓	✓	✓	
Lower energy costs			✓		✓	✓	✓	✓
Lower first costs				✓	✓	✓	✓	
Lower operations and maintenance costs					✓		✓	
Promotes innovation in the construction industry	✓	✓	✓	✓	✓	✓	✓	✓
Reductions in warranty costs			✓	✓	✓		✓	
Reductions in waste and pollution			✓	✓	✓			✓

TABLE 5 Types of Cost Increases and Benefit Reductions Classified by Stakeholder Group

Type of Cost Increase or Benefit Reduction	Stakeholder Group							
	Product Development and Testing	Codes, Standards, and Support Services	Manufacturing Interest Group	Construction and Associated Support Services	Owners/ Managers/ Developers/ Users	Professional Services	Financial Services	Other
Increased costs of adapting new construction technologies, products, equipment, and practices to industry use	✓	✓	✓	✓	✓	✓		
Increased costs for new standards development	✓	✓	✓			✓		✓
Increased investments/ expenditures by building materials/ products manufacturers	✓		✓					✓
Increased risk exposure and uncertainty due to construction with new technologies, products, equipment, or practices	✓		✓	✓	✓	✓	✓	
Reduced sales of traditional "prescriptive-oriented" building materials/products lines and associated services			✓	✓	✓	✓		✓

7. Keywords

7.1 analytical hierarchy process; building design; building economics; building materials; building systems; cost analysis; discounting; durability; economic analysis; economic evaluation methods; engineering economics; housing; investment analysis; life-cycle costing; multiattribute decision analysis; operations research methods; performance criteria; present-value analysis; residential dwellings

APPENDIXES

(Nonmandatory Information)

X1. CLASSIFICATION OF COST SAVINGS AND OTHER BENEFITS FOR SINGLE-FAMILY ATTACHED AND DETACHED DWELLINGS

X1.1 Background

X1.1.1 Use this classification to identify the economic data associated with the key types of cost savings and other benefits. This classification is presented as a hierarchy with three levels. The hierarchy incorporates an alphanumeric designation for the classification: a single letter for Level 1, a three character alphanumeric code for Level 2, and a five character alphanumeric for Level 3. Each Level 1 element corresponds to a specific entry in Tables 3 and 4. These entries appear under the column heading Type of Benefit or Cost Saving. To facilitate cross-referencing between this classification and Tables 3 and 4, the Level 1 elements are listed in the same order as their corresponding entries in Tables 3 and 4.

X1.2 Description of Cost Savings and Other Benefits

X1.2.1 *A—Exceeds Minimum Acceptable Performance:* A10 Allows increased level of performance for one or more performance attributes for a given budget

A20 More opportunities for customization

A30 More opportunities for design evaluation

A40 Opportunity to increase customer satisfaction through ability to integrate building systems/service functions across multiple performance attributes

X1.2.2 *B—Improvements in Health, Safety, and Security:* B10 Fewer construction worker accidents (injuries and fatalities) and illnesses

B1010 Lower indirect costs

B1020 Lower medical costs associated with accidents and illnesses

B1030 Lower workman's compensation insurance premiums

B20 Fewer dwelling-related accidents and illnesses for building occupants and third parties

B2010 Fewer lost workdays

B2020 Lower medical costs associated with accidents and illnesses

B2030 Lower property insurance premiums

B30 Increased productivity at home and at work for building occupants

B40 Reduced loss of property due to natural and man-made causes

B4010 Less out of pocket expenses due to coinsurance and deductibles

B4020 Lower property insurance premiums

X1.2.3 *C—Increased Occupant Comfort:* C10 Better control of temperature, humidity, indoor air quality, and lighting levels

C20 Less distraction from outside

X1.2.4 *D—Increased Sales for Building Materials/Products Manufacturers:* D10 Increased sales of materials/products with new characteristics/functions

D20 Opportunities to enter new markets because standardization promotes both domestic and international business

X1.2.5 *E—Increased Sales for Systems Design/Integration/Optimization Services:* E10 Increased sales of services aimed at packaging innovative solutions that result in higher quality at lower costs for the client

E20 Increased sales of new types of services due to the flexibility allowed under a system of performance-based standards

X1.2.6 *F—Lower Conversion Costs (Additions, Alterations, and Major Replacements):* F10 Increased adaptive reuse

F20 Less disruption to home owner during remodeling/renovation activities

F30 Lower repair and replacement costs

X1.2.7 *G—Lower Energy Costs:* G10 More opportunities for improved thermal performance of building materials/envelope system

G20 More opportunities for increasing the efficiency of mechanical/HVAC equipment

G30 More opportunities for mechanical/HVAC equipment/envelope system optimization

X1.2.8 *H—Lower First Costs:* H10 Reduced financial holding costs due to cycle time reduction through use of new construction processes and techniques

H20 More opportunities for substituting less costly inputs

X1.2.9 *I—Lower Operations and Maintenance Costs:* I10 Lower maintenance costs due to better information on durability, functionality, and maintainability

I20 Lower operating costs due to ability to integrate building systems/service functions across multiple performance attributes

X1.2.10 *J—Promotes Innovation in the Construction Industry:* J10 Faster adoption/diffusion of new construction technologies

J20 Fewer barriers to innovation

J30 Lower dissemination costs

X1.2.11 *K—Reductions in Warranty Costs:* K10 Ability to establish minimum performance requirements for a warranty based on the O-C-E-C format

K20 Improved service life predictions due to better information on durability, functionality, and maintainability.

X1.2.12 *L—Reductions in Waste and Pollution:* L10 Improved quality of life for future generations

L20 Lower negative life-cycle environmental impacts

X1.3 Benefit and Cost Savings Elements Classified by Stakeholder Group

X1.3.1 Use Table X1.1 to determine which elements are associated with the stakeholder group(s) of interest. Table X1.1 promotes a priority-setting process for data collection by limiting the data collection effort to those cells with check marks. To facilitate cross-referencing between Table X1.1 and Table 4, the rows in Table X1.1 associated with the Level 1 elements are marked by an asterisk.

TABLE X1.1 Benefit and Cost Saving Elements Classified by Stakeholder Group

Type of Benefit or Cost Saving	Stakeholder Group							
	Product Development and Testing	Codes, Standards, and Support Services	Manufacturing Interest Group	Construction and Associated Support Services	Owners/ Managers/ Developers/ Users	Professional Services	Financial Services	Other
*A				✓	✓	✓	✓	
A10					✓		✓	
A20				✓	✓	✓		
A30					✓	✓		
A40				✓	✓	✓		
*B				✓	✓	✓	✓	✓
B10				✓	✓	✓	✓	✓
B1010				✓	✓	✓	✓	✓
B1020				✓	✓	✓	✓	✓
B1030				✓	✓	✓	✓	✓
B20				✓	✓	✓	✓	✓
B2010				✓	✓	✓	✓	✓
B2020				✓	✓	✓	✓	✓
B2030					✓		✓	✓
B30					✓			✓
B40					✓	✓	✓	✓
B4010					✓		✓	
B4020					✓		✓	
*C					✓			✓
C10					✓			✓
C20					✓			✓
*D	✓	✓	✓	✓	✓	✓		✓
D10	✓	✓	✓	✓	✓	✓		✓
D20	✓	✓	✓	✓	✓	✓		
*E	✓		✓		✓	✓		
E10	✓		✓		✓	✓		
E20	✓		✓		✓	✓		
*F				✓	✓	✓	✓	
F10				✓	✓	✓	✓	
F20				✓	✓			
F30				✓	✓	✓	✓	
*G			✓		✓	✓	✓	✓
G10			✓		✓	✓		✓
G20			✓		✓	✓	✓	✓
G30			✓		✓	✓		✓
*H				✓	✓	✓	✓	
H10				✓	✓		✓	
H20				✓	✓	✓	✓	
*I					✓		✓	
I10					✓		✓	
I20					✓			
*J	✓	✓	✓	✓	✓	✓	✓	✓
J10	✓	✓	✓	✓	✓	✓	✓	✓
J20	✓	✓	✓	✓	✓	✓		✓
J30	✓		✓	✓	✓			
*K			✓	✓	✓		✓	
K10			✓	✓	✓		✓	
K20			✓	✓	✓		✓	
*L			✓	✓	✓			✓
L10			✓	✓	✓			✓
L20			✓	✓	✓			✓

X1.4 Measurement Methods for Benefit and Cost Saving Elements

X1.4.1 Use Table X1.2 to determine which measurement method to use to estimate the benefits and cost savings associated with each element. Use only those elements which apply to the stakeholder group(s) of interest (see Table X1.1). Because elements are classified in a hierarchy, certain Level 1 and Level 2 elements are composed of sub-elements with different types of measurement methods which must be combined to get the desired estimate. These cases are designated by the term “composite measure” in Table X1.2. The value of goods and services produced by the economy is measured by

TABLE X1.2 Measurement Methods for Benefit and Cost Saving Elements

Element	Measurement Method
A	Owner willingness to pay
A10	Owner willingness to pay
A20	Owner willingness to pay
A30	Owner willingness to pay
A40	Owner willingness to pay
B	Composite measure
B10	Composite measure
B1010	Indirect cost reductions due to less: lost productivity, demand for replacement workers, forms processing, damage to materials and equipment, and litigation
B1020	Reductions in medical costs
B1030	Reductions in insurance premiums
B20	Composite measure
B2010	Less loss of occupant income, corporate cost reductions due to less: lost productivity and demand for replacement-workers
B2020	Reductions in medical costs
B2030	Reductions in insurance premiums
B30	Owner willingness to pay plus corporate value of productivity gains
B40	Composite measure
B4010	Reductions in out of pocket expenses due to coinsurance and deductibles
B4020	Reductions in insurance premiums plus higher profits to insurers
C	Owner willingness to pay
C10	Owner willingness to pay
C20	Owner willingness to pay
D	Composite measure
D10	Value of increased sales
D20	Corporate willingness to pay
E	Composite measure
E10	Increased corporate sales and owner willingness to pay
E20	Increased corporate sales and owner willingness to pay
F	Composite measure
F10	Owner willingness to pay
F20	Owner willingness to pay
F30	Reductions in repair and replacement costs
G	Reductions in energy costs
G10	Reductions in energy costs
G20	Reductions in energy costs
G30	Reductions in energy costs
H	Composite measure
H10	Reductions in financial holding costs
H20	Reductions in input costs
I	Composite measure
I10	Reductions in maintenance costs
I20	Reductions in operating costs
J	Composite measure
J10	Corporate willingness to pay plus owner willingness to pay
J20	Corporate willingness to pay
J30	Reductions in dissemination costs
K	Composite measure
K10	Corporate willingness to pay for reductions in settlement costs
K20	Reductions in warranty-related replacement costs
L	Willingness to pay
L10	Willingness to pay
L20	Willingness to pay

the people's actual willingness to pay for those goods and services. The elements listed in Table X1.2 are no exception. Therefore, if a defined market for an element exists, an explicit measurement method is associated with that element (for example, reductions in medical costs for the Level 3 element B1020). If the market for an element is not defined, a variation of the term "willingness to pay" is associated with it (for example, user willingness to pay for the Level 1 Element A (exceeds minimum acceptable performance)). Thus, it will be difficult to obtain measures of the economic value that stakeholders place on such elements.

NOTE X1.1—An exception to Element A (exceeds minimum acceptable performance) being measured by the user's willingness to pay occurs when one or more alternatives offer increased service life for the durability attribute. In this case, increased service life leads to fewer replacements, resulting in a measurable difference in future costs. In such cases, there is still a user willingness to pay component because increased service life results in higher first cost. See Appendix X3 for a case example of how to use the life-cycle cost method to evaluate alternatives with different first costs and service lives.

X2. CLASSIFICATION OF COST INCREASES (OR BENEFIT REDUCTIONS) FOR SINGLE-FAMILY ATTACHED AND DETACHED DWELLINGS

X2.1 Background

X2.1.1 Use this classification to identify the economic data associated with the key types of cost increases (or benefit reductions). This classification is presented as a hierarchy with three levels. The hierarchy incorporates an alphanumeric designation for the classification: a single letter for Level 1, a three-character alphanumeric code for Level 2, and a five-character alphanumeric for Level 3. Each Level 1 element corresponds to a specific entry listed in Table 5. These entries appear under the column heading Type of Cost Increase or Benefit Reduction. To facilitate cross-referencing between this classification and Table 5, the Level 1 elements are listed in the same order as their corresponding entries in Table 5.

X2.2 Description of Cost Increases (or Benefit Reductions)

X2.2.1 *A—Increased Costs of Adapting New Construction Technologies, Products, Equipment, and Practices to Industry Use:* A10 Additional building systems infrastructure needed to integrate functions of multiple performance attributes

A20 Higher wholesale/retail inventory holding costs

A30 Increased costs for building code allowances/permits

A40 Increased training costs

A4010 Increased costs for instruction on how to incorporate new building materials/products into the design process

A4020 Increased costs to train building code officials on the O-C-E-C format and on appropriate inspection and evaluation procedures

A4030 Increased costs to train building owners/managers on proper use, maintenance, and repair of new building materials/products

A4040 Increased costs to train contractors and construction workers on new construction processes and techniques

A4050 Increased costs to train specifiers on how to use the O-C-E-C format

X2.2.2 *B—Increased Costs of New Standards Development:* B10 Higher costs associated with representation on and participation in standards committees

B20 Increased costs of developing documentation suitable for presentation to standards committees for balloting

X2.2.3 *C—Increased Investments/Expenditures by Building Materials/Products Manufacturers:* C10 Additional costs for new material inputs

C20 Additional investments in new plant and equipment

C30 Conversion costs for installing new production processes in existing facilities

C40 Increased costs for copyright/trademark registration

C50 Increased costs for product positioning

C60 Increased costs to develop new distribution and service channels

C70 Increased research and development costs

C7010 Increased costs for new building materials/products research and development activities

C7020 Increased costs for new building materials/products testing/simulation to demonstrate proof of functionality

C80 Intermediate requirement to maintain redundant services and distribution channels

X2.2.4 *D—Increased Risk Exposure and Uncertainty Due to Construction with New Technologies, Products, Equipment, or Practices:* D10 Potential for higher first costs

D20 Potential for higher legal costs due to building materials/products liability/litigation

D30 Potential for higher operations and maintenance costs

D40 Potential for more frequent repairs to and replacements of new building materials/products

X2.2.5 *E—Reduced Sales of Traditional" Prescriptive-Oriented" Building Materials/ Products Lines and Associated Services:* E10 Reduced employment in construction-related industries

E20 Reduced sales for traditional building materials/products/services for new construction activities

E30 Reduced sales for traditional building materials/products/services for maintenance and remodeling activities

X2.3 Increased Costs and Benefit Reductions Classified by Stakeholder Group

X2.3.1 Use Table X2.1 to determine which elements are associated with the stakeholder group(s) of interest. Table X2.1 promotes a priority-setting process for data collection by limiting the data collection effort to those cells with check marks. To facilitate cross-referencing between Table X2.1 and Table 5, the rows in Table X2.1 associated with the Level 1 elements are shaded.

X2.4 Measurement Methods for Increased Cost or Benefit Reduction Elements

X2.4.1 Use Table X2.2 to determine which measurement method to use to estimate the increased costs or benefit reductions associated with each element. Use only those elements which apply to the stakeholder group(s) of interest (see Table X2.1). Because elements are classified in a hierarchy, certain Level 1 and Level 2 elements are composed of sub-elements with different types of measurement methods which must be combined to get the desired estimate. These cases are designated by the term "composite measure" in Table X2.2. If a defined market for an element exists, an explicit measurement method is associated with that element. If not, a variation of the term "willingness to pay" (see X1.4) is associated with it (for example, corporate willingness to pay for Element B (increased costs of new standards development)). Because risk exposure is inherent in many new technologies, products, equipment, or practices the term" contingency" is associated with the increased cost or benefit reduction estimates for elements D10, D20, D30, and D40. A

TABLE X2.1 Increased Costs and Benefit Reductions Classified by Stakeholder Group

Type of Cost Increase or Benefit Reduction	Stakeholder Group							
	Product Development and Testing	Codes, Standards, and Support Services	Manufacturing Interest Group	Construction and Associated Support Services	Owners/ Managers/ Developers/ Users	Professional Services	Financial Services	Other
A	✓	✓	✓	✓	✓	✓		
A10	✓	✓	✓	✓	✓	✓		
A20			✓	✓				
A30		✓		✓	✓			
A40	✓	✓	✓	✓	✓	✓		
A4010	✓	✓	✓	✓	✓	✓		
A4020	✓	✓		✓	✓			
A4030					✓			
A4040				✓				
A4050		✓		✓	✓	✓		
B	✓	✓	✓			✓		✓
B10	✓	✓	✓			✓		✓
B20	✓	✓	✓			✓		✓
C	✓		✓					✓
C10	✓		✓					✓
C20	✓		✓					✓
C30	✓		✓					✓
C40	✓		✓					
C50	✓		✓					
C60	✓		✓					
C70	✓		✓					
C7010	✓		✓					
C7020	✓		✓					
C80			✓					
D	✓		✓	✓	✓	✓	✓	
D10				✓	✓		✓	
D20	✓		✓	✓	✓	✓		
D30			✓	✓	✓		✓	
D40			✓	✓	✓		✓	
E			✓	✓	✓	✓		✓
E10			✓	✓	✓	✓		✓
E20			✓	✓	✓	✓		
E30			✓	✓	✓			

contingency is a sum of money not intended to be spent. It is used as a hedge against risk exposure. It is estimated to the best of one's abilities to ensure that a financial buffer is available within a budget for the project's planned activities. This buffer is intended to assist in mitigating the effects of unplanned events and other risks that are external to the project's planned activities and so are not controllable.

TABLE X2.2 Measurement Methods for Increased Costs and Benefit Reductions

Element	Measurement Method
A	Composite measure
A10	Increased costs for building systems infrastructure
A20	Increased inventory holding costs
A30	Increased costs for building code allowances/permits
A40	Composite measure
A4010	Increased costs for instruction on how to incorporate new building materials/products into the design process
A4020	Increased costs to train building code officials on the O-C-E-C format and on appropriate inspection and evaluation procedures
A4030	Increased costs to train building owners/managers on proper use, maintenance, and repair of new building materials/products
A4040	Increased costs to train contractors and construction workers on new construction processes and techniques
A4050	Increased costs to train specifiers on how to use the O-C-E-C format
B	Corporate willingness to pay
B10	Corporate willingness to pay
B20	Corporate willingness to pay
C	Composite measure
C10	Increased costs for new material inputs
C20	Increased investment costs for new plant and equipment
C30	Costs of conversion
C40	Increased costs for copyright/trademark registration
C50	Increased costs for product positions
C60	Increased costs to develop new distribution and service channels
C70	Composite measure
C7010	Increased costs for new building materials/products research and development activities
C7020	Increased costs for new building materials/products testing/simulation to demonstrate “proof of functionality”
C80	Increased costs to maintain redundant services and distribution channels
D	Composite measure
D10	Contingency held to cover unexpected financial holding costs or cost overruns
D20	Contingency held to cover unexpected legal costs due to building materials/products liability/litigation
D30	Contingency held to cover unexpected operations and maintenance costs
D40	Contingency held to cover unexpected repair and replacement costs
E	Composite measure
E10	Lost income to employee, cost of severance pay, and increases in unemployment insurance
E20	Reduced sales for traditional building materials/products/services for new construction activities
E30	Reduced sales for traditional building materials/products/services for maintenance and remodeling activities

X3. PROBLEM EXAMPLE: WALL-TO-WALL CARPET

X3.1 Background

X3.1.1 This example shows how to pair economic evaluation with the durability attribute. When appropriate, cross references to specific sections in the Standard Guide for Durability are provided. In this example, the specifier is the manager for a large inventory of public housing. The specifier first selects the durability attribute. The specifier then selects element 4.2.1, floors, within the hierarchy of building elements. Consideration is limited to wall-to-wall carpet. A performance statement is included (see X3.1.1.1) to define the minimum level of performance that the specifier will accept from providers. The specifier decides to use the life-cycle cost (LCC) method (Practice E917) to evaluate economic performance. The specifier determines that two types of cost savings are anticipated: (*1*) exceeds minimum acceptable performance; and (*2*) lower operations and maintenance costs. Only one type of cost is anticipated, increased risk exposure. In this case, increased risk exposure is due to uncertainty about each alternative’s first costs, replacement costs, and the replacement schedule. The specifier requests providers to include in their responses to the request for proposals the cost to purchase and install the carpet, the average durability of the carpet in years,

the likely minimum and maximum durability of the carpet in years, and the annual cost to maintain the carpet. All costs reported in the providers' responses include their markups for overhead and profit.

X3.1.1.1 *Performance Statements*—In Durability, the Minimum Anticipated Service Life for wall-to-wall carpet (4.2.1 Floors) is suggested as a range from 3 to 20 years. The specifier, in accordance with 5.2.1 of Durability, has specified the minimum anticipated service life as 10 years. The specifier has applied this number to Performance Statements 4.A and 4.B (C-1, C-2, and C-6), and has adjusted the exposure rates in E-1, E-2, and E-6 of 4.B to correspond to the 10-year minimum anticipated service life. Three providers have submitted proposals that include wall-to-wall carpet. One provider claims to comply by offering a product with a minimum anticipated serve life of 10 years but an average service life of 12 years. Two providers claim their products exceed the 10 year minimum by offering products with minimum anticipated service lives of 15 and 20 years, respectively. They document their claims by EM-1 (for Performance Statement 4.A), as well as by the use of higher exposure rates under E-1, E-2, and E-6 (for Performance Statement 4.B).

X3.1.1.2 *Alternatives Considered*—Three are under consideration: (*1*) a minimum-acceptable-performance product; (*2*) a common-use product; and (*3*) an innovative product.

X3.1.1.3 *Goal*—To determine with the life-cycle cost (LCC) method (Practice E917) the most cost-effective wall-to-wall carpeting alternative to be used in this inventory of public housing. The specifier wishes to use a LCC analysis to evaluate the economic consequences of variations in the durability of each carpeting alternative, where the durability of each carpeting alternative is measured in years. Variations in product durability translate into variations in initial cost (measured by the cost to purchase and install each carpeting alternative), the replacement cost, the replacement schedule (a multiple of the durability of each carpeting alternative, where durability is equal to asset life), and annual maintenance and repair costs. The most cost-effective carpeting alternative is defined as the one that minimizes the value of LCC over the length of the study period and meets the prescribed performance requirements.

X3.1.1.4 *Length of Study Period*—The length of the study period over which LCC is to be measured is 25 years.

X3.1.1.5 *Types of Analysis*—Three types of analysis employing the LCC method are presented: (*1*) baseline analysis; (*2*) sensitivity analysis; and (*3*) Monte Carlo simulation. The first type of analysis sets all input variables at their expected values. The term baseline analysis is used to denote a complete LCC analysis in all respects but one; it does not address the effects of uncertainty. Sensitivity analysis measures the impact on LCC of changing the value of one or more input variables about which there is uncertainty. A sensitivity analysis complements the baseline analysis by evaluating the changes in LCC when selected sets of input variables vary about their baseline values. Monte Carlo simulation is a well-documented technique used to determine risk exposure from an investment decision. A Monte Carlo simulation complements both the baseline analysis and the sensitivity analysis because it permits probabilistic levels of significance to be attached to the computed values of LCC for each alternative under consideration.

X3.1.1.6 *Special Considerations*—Three input variables are subjected to in-depth analyses. These input variables are: (*1*) the discount rate; (*2*) initial cost; and (*3*) the replacement schedule. In-depth analyses are used to demonstrate how changes in the three input variables, both singly and in combination, affect the LCC of each alternative. Data and information compiled from the providers' responses and additional data and information compiled by the specifier are used to set up ranges of values for the input variables subjected to in-depth analyses.

X3.2 Baseline Analysis

X3.2.1 The baseline analysis is a direct application of the LCC method as specified in Practice E917. The data and assumptions used in the baseline analysis are listed in Table X3.1. All costs are stated in 1997 dollars, the study period spans 25 years (from 1997 to 2021), and all costs are discounted using a 7 % real discount rate. Tables X3.2-X3.4 give the year-by-year results and the resultant LCC for the minimum-acceptable-performance product, the common-use product, and the innovative product, respectively. To facilitate comparisons among the three tables, each column is labeled with a heading and is numbered. For example, Column 1 records the year in the study period, Column 2 records the calendar year, and Column 7 records the present value factor. The present value factors recorded in Column 7 are calculated on the implicit assumption that with the exception of initial investment cost all costs occur as lump sums at year end. Reference to Columns 1 and 2 of Tables X3.2-X3.4 show that the first two entries under Column 1 correspond to calendar year 1997. This is because the initial investment cost occurs at the start of the study period (that is, the beginning of 1997). Thus, the present value factor for the initial investment cost is 1.000. Since all costs recorded in Tables X3.2-X3.4 are rounded to the nearest cent, the sums across a given row may differ from the values recorded in Column 6 of that row. Similarly, the sums down Column 8 in Tables X3.2-X3.4 may differ from the resultant LCC given in the last row of the respective table. Table X3.5 gives the LCC for each alternative evaluated in the baseline analysis. These results indicate that the innovative product is the most cost-effective alternative and the minimum-acceptable-performance-product is the least cost-effective alternative.

X3.3 Sensitivity Analysis

X3.3.1 The sensitivity analysis expands the application of the LCC method by employing the procedure given in 7.3 of Guide E1369. Tables X3.6-X3.8 show how the LCC of each alternative varies when each of three input variables-the discount rate, first cost, and the replacement schedule—are set at their minimum and maximum anticipated values, respectively. The range of values for the discount rate is a low of 2 % and a high of 10 %. The range of values for the initial cost of each alternative is a low of $2.69 per square metre less than the baseline value and a high of $2.69 per square metre more than the baseline value. The range of values for the replacement

TABLE X3.1 Summary of Values for the Input Variables Used in the Baseline Analysis of the Three Wall-to-Wall Carpet Alternatives

Study period (investor's holding period)	25 years
Discount rate (real)	7 %
Inflation rate	0 %[A]
Replacement schedule (multiple of asset life)	
Asset life	
Minimum-acceptable-performance product	12 years
Common-use product	15 years
Innovative product	20 years
Cost data[B]	Cost per square metre[C]
Investment cost data	
Purchase and installation	
Minimum-acceptable-performance product	$16.15
Common-use product	$21.53
Innovative product	$26.91
Replacement cost[D]	
Minimum-acceptable-performance product	$18.84
Common-use product	$24.22
Innovative product	$29.60
Residual value (straight line)	
Minimum-acceptable-performance product	$14.80
Common-use product	$7.18
Innovative product	$20.18
Annually recurring maintenance and repair costs	
Minimum-acceptable-performance product[E]	$1.61
Common-use product[F]	$1.08
Innovative product[F]	$0.54

[A] Values in the table are expressed in constant 1997 dollars.
[B] Cost data are derived from unit price figures published in cost-estimating guides.
[C] Unit price figures for carpet installation are normally expressed in customary units. In this appendix, however, they are quoted on a per square metre basis to conform with the use of SI units in ASTM standards. To convert the cost per square metre to the cost per square yard, multiply the cost per square metre by 0.8361. If cost per square foot is desired, multiply the cost per square metre by 0.0929. For example, the cost to purchase and install the Common-Use Product is $21.53 per square metre, which equals $18.00 per square yard, or $2.00 per square foot.
[D] Replacement cost equals the cost to purchase and install each carpet alternative plus the cost to remove and dispose of the old carpet of $2.69 per square metre for each carpet alternative.
[E] 0 % escalation rate (expressed as a real escalation rate).
[F] –2 % escalation rate (expressed as a real escalation rate).

schedule varies by alternative. Sooner replacement entails more frequent replacements vis-à-vis the baseline replacement schedule. Later replacement entails less frequent replacements *vis-à-vis* the baseline replacement schedule. Each input variable produces a set of LCC values within this part of the sensitivity analysis. Table X3.9 shows how the LCC of each alternative varies when all three of the input variables are set at their most favorable and least favorable combinations. The most favorable combination corresponds to a 10 % discount rate, a low initial cost, and a later replacement schedule. Each of the settings in the most favorable combination when applied singly resulted in low values for LCC. Thus, when all three settings are applied in combination, they result in even lower values for LCC. The least favorable combination corresponds to a 2 % discount rate, a high initial cost, and a sooner replacement schedule. Each of the settings in the least favorable combination when applied singly resulted in high values for LCC. Thus, when all three settings are applied in combination, they result in even higher values for LCC. Although the LCC values calculated within each set and across all four sets of the sensitivity analysis varied considerably, the rank ordering of the alternatives remained the same. In all four sets of LCC values calculated in the sensitivity analysis, the innovative product is the most cost effective and the minimum-acceptable-performance-product is the least cost effective.

X3.4 Monte Carlo Simulation

X3.4.1 The Monte Carlo simulation further expands the application of the LCC method by employing the procedure given in 7.7 of Guide E1369. Table X3.10 lists the types of probability distributions used to model variations about the baseline value of each input variable, the baseline value, and the appropriate ranges that were used in a series of Monte Carlo simulations.[7] Two probability distributions[8] are used: (*1*) the triangular and (*2*) the discrete. The triangular distribution is used whenever the range of values is continuous and a clustering about some central value is expected. The triangular distribution was used for two input variables: (*1*) the discount rate and (*2*) initial cost. The discrete distribution is used whenever the range of values is discrete; in this case, it is tied into the year in the study period (see Column 1 of Tables X3.2-X3.4). The discrete distribution is used to model the replacement schedule (see Column 3 of Tables X3.2-X3.4). Four sets of Monte Carlo simulations were performed—one for each of the three input variables run singly and one for all three input variables run in combination. Figs. X3.1-X3.4 and Tables X3.11-X3.14 document the outcomes of each of the four sets of Monte Carlo simulations. Each figure shows a cumulative distribution function of LCC values for each alternative. The vertical axis in each figure records the probability that LCC is less than or equal to a specified value on the horizontal axis (see Fig. X3.1). A range of values for LCC is recorded on the horizontal axis of each figure. A movement of the cumulative distribution function to the left indicates lower values of LCC, whereas a movement to the right indicates higher values of LCC. Each alternative is represented by a trace on the figure. The table associated with each figure summarizes the statistics from the Monte Carlo simulation. In each set of Monte Carlo simulations, it is evident that the innovative product has the lowest LCC. In all cases, the trace of the innovative product lies to the left of the other alternatives.

X3.5 Decision

X3.5.1 Based on the LCC calculations performed in all three types of analysis, it is most cost effective to use the innovative product as the type of carpeting in the public housing units, given the three alternatives analyzed in this problem.

[7] The range of values employed in the Monte Carlo simulations for each input variable, both singly and in combination, is the same as the range employed in the sensitivity analysis.
[8] For additional information on these and other probability distributions, including variate relationships, estimating procedures, and random number generation, see Evans, Hastings, and Peacock, (Evans, Merran, Nicholas Hastings, and Brian Peacock, 1993. *Statistical Distributions*. New York, NY: John Wiley & Sons, Inc.).

TABLE X3.2 Baseline Analysis LCC Calculations for the Minimum Acceptable Performance Product

Year in Study Period	Calendar Year	Capital Cost	Maintenance and Repair Costs	Residual Value	Total Cost	Present Value Factor	PV Cost
Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6) (3)+(4)+(5)	Column (7)	Column (8) (6)*(7)
0	1997	16.15	0.00	0.00	16.15	1.000	16.15
1	1997	0.00	1.61	0.00	1.61	0.935	1.50
2	1998	0.00	1.61	0.00	1.61	0.873	1.41
3	1999	0.00	1.61	0.00	1.61	0.816	1.31
4	2000	0.00	1.61	0.00	1.61	0.763	1.23
5	2001	0.00	1.61	0.00	1.61	0.713	1.15
6	2002	0.00	1.61	0.00	1.61	0.666	1.07
7	2003	0.00	1.61	0.00	1.61	0.623	1.00
8	2004	0.00	1.61	0.00	1.61	0.582	0.94
9	2005	0.00	1.61	0.00	1.61	0.544	0.88
10	2006	0.00	1.61	0.00	1.61	0.508	0.82
11	2007	0.00	1.61	0.00	1.61	0.475	0.76
12	2008	18.84	1.61	0.00	20.45	0.444	9.08
13	2009	0.00	1.61	0.00	1.61	0.415	0.67
14	2010	0.00	1.61	0.00	1.61	0.388	0.62
15	2011	0.00	1.61	0.00	1.61	0.362	0.58
16	2012	0.00	1.61	0.00	1.61	0.339	0.55
17	2013	0.00	1.61	0.00	1.61	0.317	0.51
18	2014	0.00	1.61	0.00	1.61	0.296	0.48
19	2015	0.00	1.61	0.00	1.61	0.277	0.45
20	2016	0.00	1.61	0.00	1.61	0.258	0.42
21	2017	0.00	1.61	0.00	1.61	0.242	0.39
22	2018	0.00	1.61	0.00	1.61	0.226	0.36
23	2019	0.00	1.61	0.00	1.61	0.211	0.34
24	2020	18.84	1.61	0.00	20.45	0.197	4.03
25	2021	0.00	1.61	–14.80	–13.19	0.184	–2.43
Present value of cost per square metre in 1997 dollars							$44.26

TABLE X3.3 Baseline Analysis LCC Calculations for the Common Use Product

Year in Study Period	Calendar Year	Capital Cost	Maintenance and Repair Costs	Residual Value	Total Cost	Present Value Factor	PV Cost
Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6) (3)+(4)+(5)	Column (7)	Column (8) (6)*(7)
0	1997	21.53	0.00	0.00	21.53	1.000	21.53
1	1997	0.00	1.08	0.00	1.08	0.935	1.01
2	1998	0.00	1.06	0.00	1.06	0.873	0.92
3	1999	0.00	1.04	0.00	1.04	0.816	0.85
4	2000	0.00	1.02	0.00	1.02	0.763	0.78
5	2001	0.00	1.00	0.00	1.00	0.713	0.71
6	2002	0.00	0.98	0.00	0.98	0.666	0.65
7	2003	0.00	0.96	0.00	0.96	0.623	0.60
8	2004	0.00	0.94	0.00	0.94	0.582	0.55
9	2005	0.00	0.92	0.00	0.92	0.544	0.50
10	2006	0.00	0.90	0.00	0.90	0.508	0.46
11	2007	0.00	0.89	0.00	0.89	0.475	0.42
12	2008	0.00	0.87	0.00	0.87	0.444	0.39
13	2009	0.00	0.85	0.00	0.85	0.415	0.35
14	2010	0.00	0.83	0.00	0.83	0.388	0.32
15	2011	24.22	0.82	0.00	25.04	0.362	9.08
16	2012	0.00	0.80	0.00	0.80	0.339	0.27
17	2013	0.00	0.79	0.00	0.79	0.317	0.25
18	2014	0.00	0.77	0.00	0.77	0.296	0.23
19	2015	0.00	0.76	0.00	0.76	0.277	0.21
20	2016	0.00	0.74	0.00	0.74	0.258	0.19
21	2017	0.00	0.73	0.00	0.73	0.242	0.18
22	2018	0.00	0.71	0.00	0.71	0.226	0.16
23	2019	0.00	0.70	0.00	0.70	0.211	0.15
24	2020	0.00	0.68	0.00	0.68	0.197	0.14
25	2021	0.00	0.67	–7.18	–6.51	0.184	–1.20
Present value of cost per square metre in 1997 dollars							$39.69

TABLE X3.4 Baseline Analysis LCC Calculations for the Innovative Product

Year in Study Period	Calendar Year	Capital Cost	Maintenance and Repair Costs	Residual Value	Total Cost	Present Value Factor	PV Cost
Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6) (3)+(4)+(5)	Column (7)	Column (8) (6)*(7)
0	1997	26.91	0.00	0.00	26.91	1.000	26.91
1	1997	0.00	0.54	0.00	0.54	0.935	0.50
2	1998	0.00	0.53	0.00	0.53	0.873	0.46
3	1999	0.00	0.52	0.00	0.52	0.816	0.42
4	2000	0.00	0.51	0.00	0.51	0.763	0.39
5	2001	0.00	0.50	0.00	0.50	0.713	0.36
6	2002	0.00	0.49	0.00	0.49	0.666	0.33
7	2003	0.00	0.48	0.00	0.48	0.623	0.30
8	2004	0.00	0.47	0.00	0.47	0.582	0.27
9	2005	0.00	0.46	0.00	0.46	0.544	0.25
10	2006	0.00	0.45	0.00	0.45	0.508	0.23
11	2007	0.00	0.44	0.00	0.44	0.475	0.21
12	2008	0.00	0.43	0.00	0.43	0.444	0.19
13	2009	0.00	0.43	0.00	0.43	0.415	0.18
14	2010	0.00	0.42	0.00	0.42	0.388	0.16
15	2011	0.00	0.41	0.00	0.41	0.362	0.15
16	2012	0.00	0.40	0.00	0.40	0.339	0.14
17	2013	0.00	0.39	0.00	0.39	0.317	0.12
18	2014	0.00	0.39	0.00	0.39	0.296	0.11
19	2015	0.00	0.38	0.00	0.38	0.277	0.10
20	2016	29.60	0.37	0.00	29.97	0.258	7.74
21	2017	0.00	0.36	0.00	0.36	0.242	0.09
22	2018	0.00	0.36	0.00	0.36	0.226	0.08
23	2019	0.00	0.35	0.00	0.35	0.211	0.07
24	2020	0.00	0.34	0.00	0.34	0.197	0.07
25	2021	0.00	0.34	–20.18	–19.85	0.184	–3.66
Present value of cost per square metre in 1997 dollars							$36.19

TABLE X3.5 Summary of the Results of the LCC Baseline Analysis

Alternative	Present Value of Costs in 1997 Dollars
Minimum acceptable	$44.26
Common use product	$39.69
Innovative product	$36.19

TABLE X3.6 Results of the Sensitivity Analysis: Range of LCC Values Due to Extreme Values of the Discount Rate

Alternative	Present Value of Costs in 1997 Dollars	
	2 %	10 %
Minimum acceptable	$65.13	$37.31
Common use product	$52.29	$35.19
Innovative product	$43.10	$33.71

TABLE X3.7 Results of the Sensitivity Analysis: Range of LCC Values Due to Extreme Values of the Initial Cost

Alternative	Present Value of Costs in 1997 Dollars	
	Low	High
Minimum acceptable	$40.29	$48.22
Common use product	$36.19	$43.18
Innovative product	$33.18	$39.20

TABLE X3.8 Results of the Sensitivity Analysis: Range of LCC Values Due to Extreme Values of the Replacement Schedule

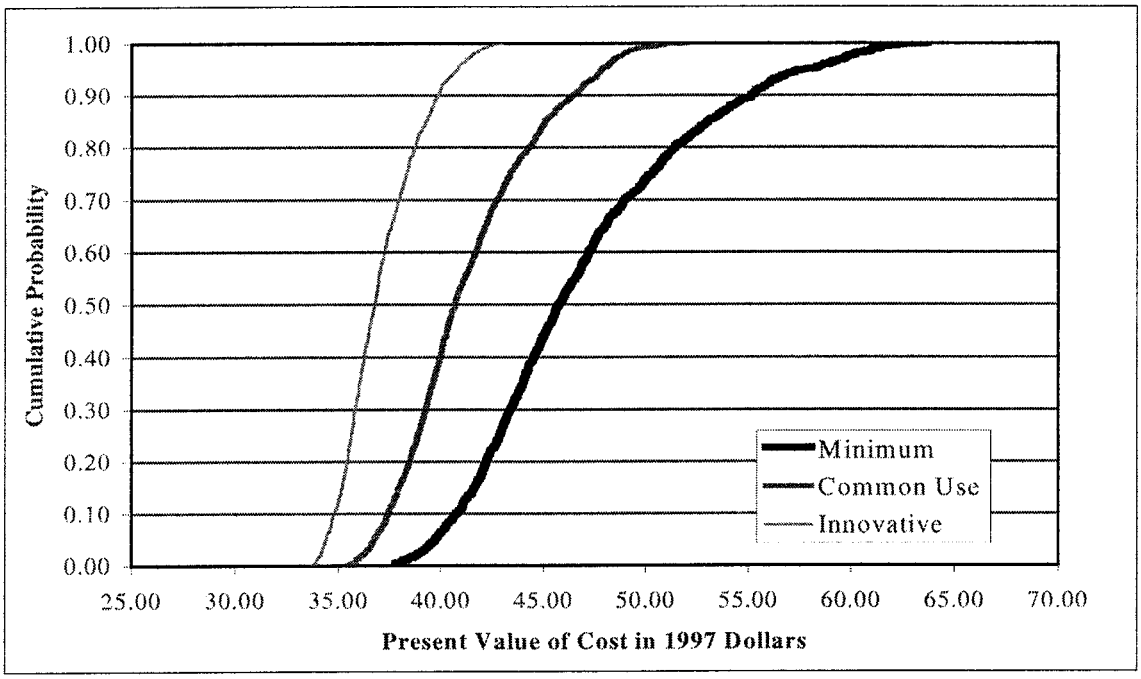
Alternative	Present Value of Costs in 1997 Dollars	
	Sooner	Later
Minimum acceptable	$47.87	$41.58
Common use product	$44.12	$36.97
Innovative product	$40.12	$33.34

TABLE X3.9 Results of the Sensitivity Analysis: Range of LCC Values Due to Extreme Values of All Three Variables

Alternative	Present Value of Costs in 1997 Dollars	
	Most Favorable Combination	Least Favorable Combination
Minimum acceptable	$32.05	$76.68
Common use product	$30.17	$65.77
Innovative product	$29.07	$53.80

TABLE X3.10 Specifications for the Probability Distributions of the Input Variables Used in the Monte Carlo Simulations

Variable Name	Probability Distribution	Range		
		Baseline Value	Minimum	Maximum
Discount rate (expressed as a decimal)	triangular	0.07	0.02	0.10
Initial cost ($ per square meter)				
Minimum acceptable	triangular	$16.15	$13.46	$18.84
Common use product	triangular	$21.53	$18.84	$24.22
Innovative product	triangular	$26.91	$24.22	$29.60
Replacement schedule (asset life in years)				
Minimum acceptable	discrete	12	10	14
Common use product	discrete	15	12	18
Innovative product	discrete	20	16	24



NOTE 1—To estimate the probability that the cost per square metre is less than or equal to a given amount, choose a value on the horizontal axis and draw a vertical line up to the point where it intersects the trace of the alternative(s) of interest. For example, the probability that the LCC (present value of cost) per square metre is less than or equal to $40.00 is approximately 0.05 for the minimum-acceptable-performance product, 0.40 for the common-use product, and 0.90 for the innovative product.

FIG. X3.1 Cumulative Distribution Function of the Present Value of Cost Due to Changes in the Discount Rate

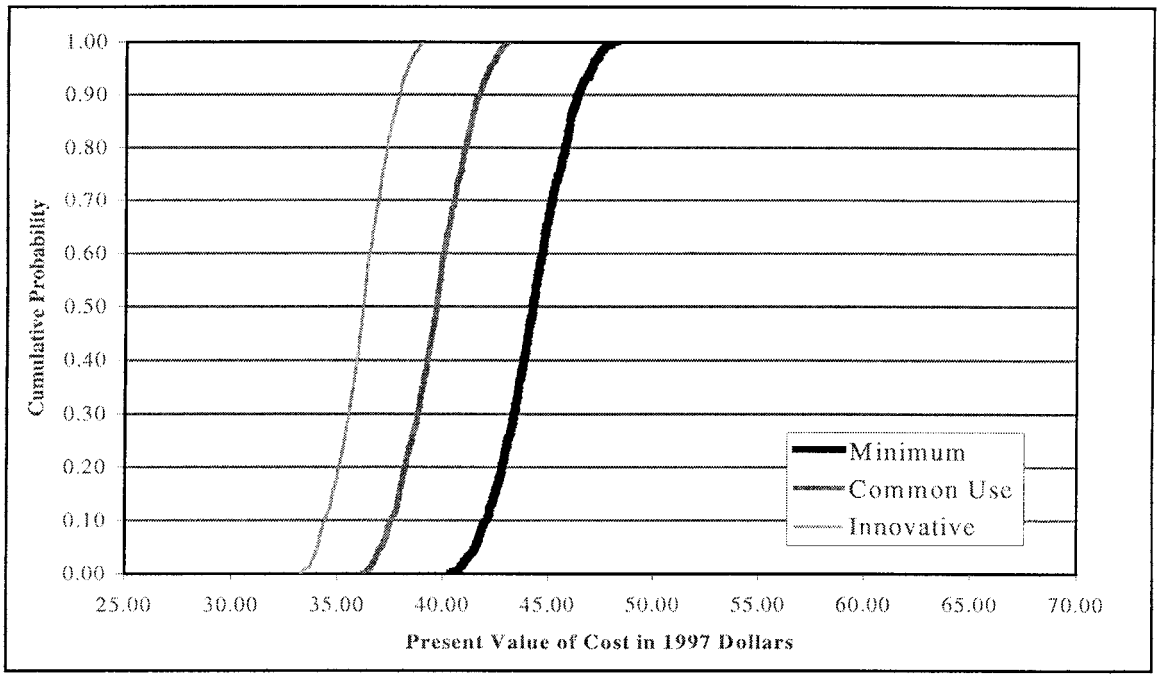


FIG. X3.2 Cumulative Distribution Function of the Present Value of Cost Due to Changes in Initial Cost

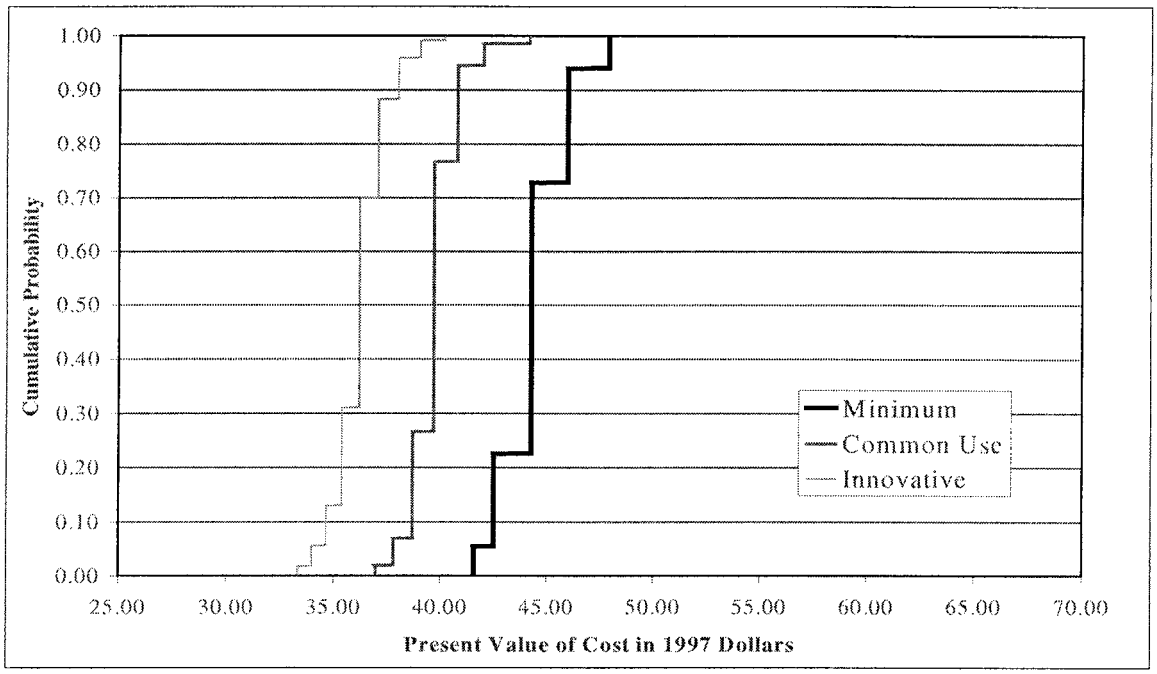
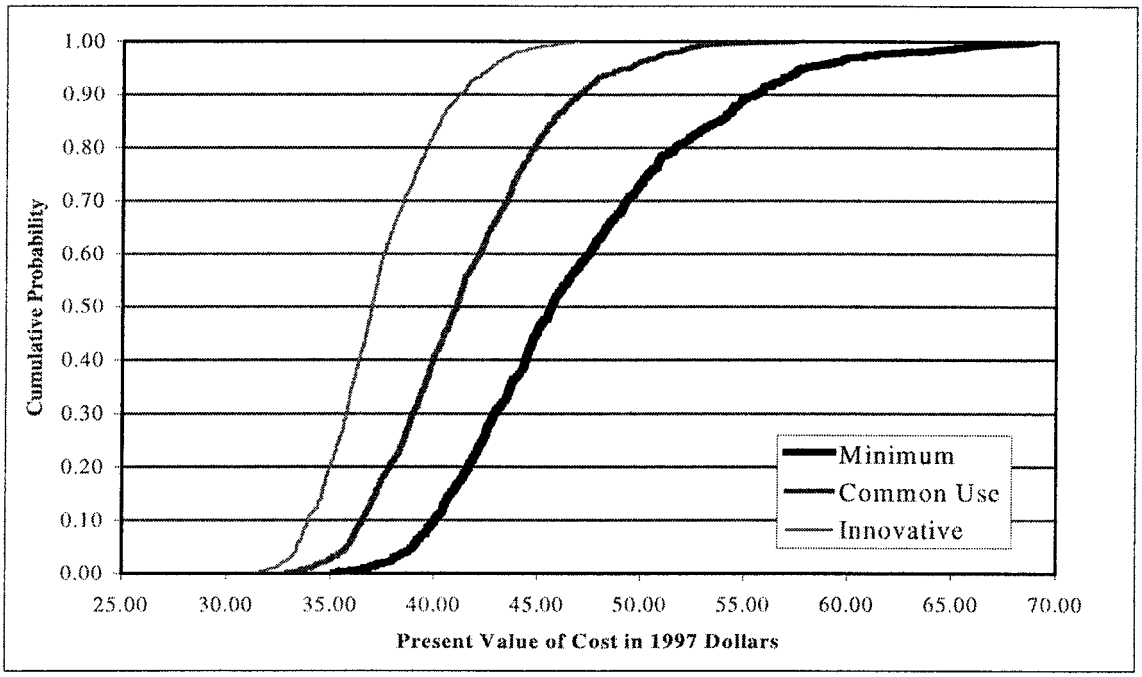


FIG. X3.3 Cumulative Distribution Function of the Present Value of Cost Due to Changes in the Replacement Schedule



NOTE 1—Both the common use product and the innovative product exceeded the minimum anticipated service of life of 10 years. If the specifier had a life-cycle cost budget target of $40.00 per square metre (see element A10 in X1.2), then the common use product will meet that budget target with a probability of 0.40 whereas the innovative product will meet it with a probability of 0.85.

FIG. X3.4 Cumulative Distribution Function of the Present Value of Cost Due to Changes in All Three Variables

TABLE X3.11 Summary Statistics Due to Changes in the Discount Rate

Alternative	Present Value of Costs in 1997 Dollars						
	Minimum	25 %	50 %	75 %	Maximum	Mean	Standard Deviation
Minimum	$37.74	$42.87	$45.74	$50.30	$63.70	$46.92	$5.45
Common use	$35.49	$38.86	$40.67	$43.37	$51.96	$41.35	$3.34
Innovative	$33.74	$35.62	$36.77	$38.31	$42.98	$37.07	$1.91

TABLE X3.12 Summary Statistics Due to Changes in the Initial Cost

Alternative	Present Value of Costs in 1997 Dollars						
	Minimum	25 %	50 %	75 %	Maximum	Mean	Standard Deviation
Minimum	$40.37	$43.08	$44.24	$45.45	$48.18	$44.25	$1.61
Common use	$36.21	$38.51	$39.66	$40.76	$43.10	$39.63	$1.51
Innovative	$33.27	$35.34	$36.20	$37.06	$38.98	$36.18	$1.24

TABLE X3.13 Summary Statistics Due to Changes in the Replacement Schedule

Alternative	Present Value of Costs in 1997 Dollars						
	Minimum	25 %	50 %	75 %	Maximum	Mean	Standard Deviation
Minimum	$41.58	$44.26	$44.26	$45.95	$47.86	$44.39	$1.51
Common use	$36.97	$38.70	$39.69	$39.69	$44.12	$39.70	$1.11
Innovative	$33.34	$35.39	$36.19	$37.05	$40.12	$36.22	$1.18

TABLE X3.14 Summary Statistics Due to Changes in All Three Variables

Alternative	Present Value of Costs in 1997 Dollars						
	Minimum	25 %	50 %	75 %	Maximum	Mean	Standard Deviation
Minimum	$35.21	$42.36	$45.66	$50.31	$68.89	$46.88	$6.12
Common use	$32.84	$38.54	$41.07	$43.99	$57.43	$41.50	$4.12
Innovative	$31.36	$35.40	$36.97	$39.02	$46.92	$37.35	$2.78